"AN OBSERVATIONAL STUDY TO ASSESS CHANGES IN TOOTH COLOR AND ORAL HYGIENE STATUS OF PATIENTS DURING FIXED ORTHODONTIC TREATMENT"

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In the Speciality of

ORTHODONTICS & DENTOFACIAL ORTHOPEDICS

Deemed to be University

(Established u/s 3 of the UGC Act, 1956)

By

Dr. KOMAL GARJE

Under the guidance of

Dr. NISHANT GUPTA

Professor

DEPARTMENT OF ORTHODONTICS & DENTOFACIAL ORTHOPEDICS

SANTOSH DENTAL COLLEGE & HOSPITALS

GHAZIABAD- 201009, NCR DELHI, INDIA

Batch 2022

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I, Dr. Komal Garje hereby, declare that this dissertation entitled is a bonafide genuine research carried out by me under the esteemed able guidance of my guide **Dr. NISHANT GUPTA, (MDS),** Professor, Department of Orthodontics & Dentofacial Orthopedics, Santosh Dental College & Hospitals, Ghaziabad, NCR Delhi & Co-Guide **Dr. TINA CHUGH**, **(MDS),** Reader, Department of Orthodontics & Dentofacial Orthopedics, Santosh Dental College & Hospitals, Ghaziabad, NCR Delhi.

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(Prof) Dr. AKSHAY BHARGAVA

DEAN
MDS (Prosthodontics)
AFAAID, DICOI, DWCOI
Santosh Dental College and Hospitals,
Ghaziabad, NCR Delhi

Date:

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GUIDE:

Dr. NISHANT GUPTA

Professor
Department of Orthodontics & Dentofacial Orthopedics
Santosh Dental College & Hospitals
Ghaziabad, NCR Delhi.

CO-GUIDE:

Dr. TINA CHUGH

Reader
Department of Orthodontics & Dentofacial Orthopedics
Santosh Dental College & Hospitals
Ghaziabad, NCR Delhi.

Deemed to be University
(Established u/s 3 of the UGC Act, 1956)

CERTIFICATE BY HEAD OF THE DEPARTMENT

This is to certify that the dissertation entitled **"AN OBSERVATIONAL STUDY TO ASSESS CHANGES IN TOOTH COLOR AND ORAL HYGIENE STATUS OF PATIENTS DURING FIXED ORTHODONTIC TREATMENT"** being submitted by Dr. KOMAL GARJE in partial fulfillment of regulation for the award of the degree of Master of Dental Surgery in the specialty of Orthodontics & Dentofacial Orthopedics is based on the bonafide work carried out by her under my direct guidance and supervision and completed to my full satisfaction.

Dr. RAJIV AHLUWALIA

Professor and H.O.D.
Department of Orthodontics &
Dentofacial Orthopedics
Santosh Dental College & Hospitals
Ghaziabad, NCR Delhi

Deemed to be University
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Dr. JYOTI BATRA

Date:

DEAN RESEARCH

Place:

SANTOSH DEEMED TO BE UNIVERSITY

Dedicated to My

Respected Teachers,

Beloved Parents, My

Brother and My

Friends

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"Every milestone achieved is rarely the triumph of one it is the symphony of many hearts beating in harmony with your dream. True gratitude is born from the soul's deepest realization that behind every success story stands a constellation of mentors, well-wishers, silent supporters, and tireless companions. It is their faith that becomes your foundation, their words that become your strength, and their presence that becomes your guiding light. This thesis, though bearing my name, is a reflection of countless acts of kindness, wisdom shared in humility, and sacrifices made in silence. I offer this work not as a personal achievement, but as a tribute to all those whose unwavering belief helped me rise, even when I doubted my own wings."

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Contents

CONTENTS

S.NO	TITLE	PAGE NO
1	Introduction	1-5
2	Aims & Objectives	6-8
3	Review of Literature	9-46
4	Materials & Method	47-65
5	Results	66-94
6	Discussion	95-109
7	Conclusion	110-113
8	Summary	114-116
9	Bibliography	117-125
10	Annexure	126-139

LIST OF FIGURES

FIG.NO	TITLE	PAGE NO
1	Vita Easyshade® Advance 4.0 (Vita Zahnfabrik, Bad Sackingen, Germany)	51
2	Check Retractor	52
3	Erythrosine Dye (Plaque Disclosing Agent)	52
4	Applicator Tip	53
5	Mouth Mirror, Prob Kidney Tray	53
6	Oral Hygiene Evaluation using Erythrosine Dye	57
7	Oral Prophylaxis Using Ultrasonic Scaler	57
8	Tooth polishing with slow speed contra angle handpiece	58
9	Recalibration Vita Easyshade® Advance 4.0	58
10	Tooth Colour Evaluation Cervical Aspect of Tooth	59
11	Tooth Colour Evaluation Mesial Aspect of Tooth	59
12	Tooth Colour Evaluation Distal Aspect of Tooth	60
13	Tooth Colour Evaluation Incisal Aspect of Tooth	60
14 (a)	Patient Case Record Sheet	61
14 (b)	Patient Case Record Sheet	62
14(c)	Patient Case Record Sheet	63
14(d)	Patient Case Record Sheet	64

LIST OF TABLES

S.NO	TABLE	PAGE NO
Table 1	Age Distribution mean and std deviation	67
Table 2	Gender Distribution mean and std deviation	67
Table 3	Evaluation Of Lightness (L) In Maxillary Anterior Teeth at T0, T1, And T2 For Cervical, Mesial, Distal and Incisal Surfaces.	67-69
Table 4	Evaluation Of Chroma (C) In Maxillary Anterior Teeth at T0, T1, And T2 For Cervical, Mesial, Distal and Incisal Surfaces: -	71-73
Table 5	Evaluation Of Hue (h) In Maxillary Anterior Teeth at T0, T1, And T2 For Cervical, Mesial, Distal and Incisal Surfaces	75-77
Table 6	Pairwise Comparison by Tukey's Test for Lightness Between T0, T1 And T2	79-80
Table 7	Pairwise Comparison by Tukey's Test for Chroma Between T0, T1 And T2	81-83
Table 8	Pairwise Comparison by Tukey's Test for Hue Between T0, T1 And T2	84-85
Table 9	Mean ΔE Of Maxillary Teeth at T1, And T2 For Cervical, Mesial, Distal and Incisal Surfaces	86-87
Table 10	Pairwise Comparison Using Tukey's Test For ΔE Values Between T1 And T2 Across All Maxillary Anterior Teeth and Surfaces	89
Table 11	Mean Oral Hygiene of Maxillary Anterior Teeth T0, T1, And T2.	91
Table 12	Pairwise Comparison Using Tukey's Test for Oral Hygiene Status Between T0, T1 And T2 Across All Maxillary Anterior Teeth	92
Table 13	Table No.12 Pairwise Comparison Using Tukey's Test for Oral Hygiene Status Between T0, T1 And T2 Across All Maxillary Anterior Teeth.	93

LIST OF ANNEXURES

S.NO	TITLE	PAGE NO
1	Patient Consent Forms	127
2	Patient Consent Forms	128-136
3	Ethical Clearance Certificate	137
4	Anti- Plagiarism Report	138-139

LIST OF ABBREVIATION

S.NO	ABBREVIATION	FULL FORM
1	L	Lightness (value representing brightness in the CIELAB color system)
2	C	Chroma (saturation or intensity of color)
3	h	Hue angle (color shade based on wavelength)
4	ΔE	Delta E (overall color difference calculated from L, a, b values)
5	OPI	Orthodontic Plaque Index
6	PI	Plaque Index
7	GI	Gingival Index
8	GBI	Gingival Bleeding Index
9	DMFT	Decayed, Missing, and Filled Teeth Index
10	WSL	White Spot Lesion
11	T0	Time Point 0 (Day of bonding)
12	T1	Time Point 1 (3 months after bonding)
13	T2	Time Point 2 (6 months after bonding)
14	SD	Standard Deviation
15	ANOVA	Analysis of Variance
16	SPSS	Statistical Package for the Social Sciences
17	ICC	Intraclass Correlation Coefficient
18	CIE	Commission Internationale de l'Éclairage (International Commission on Illumination)

19	Munsell System	Color measurement system defining hue, value, and chroma
20	RMGIC	Resin-Modified Glass Ionomer Cement
21	MDA	Mean Difference Analysis
22	SEM	Scanning Electron Microscope
23	PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses

Introduction

INTRODUCTION

Fixed orthodontic appliances constitute a critical component of contemporary orthodontic therapy. The widespread popularity of fixed appliances was significantly facilitated by the development of enamel etching technique, which substantially improved bond strength between orthodontic bracket and enamel.[1] Microscopic analysis of etched enamel showed presence of micro and macroporosities in which resin material infiltrates and forms micro and macro resin tags of up to 25 μm thus improving micromechanical retention.[2] Fixed appliances are well-documented in literature for their ability to achieve orthodontic tooth movement and favorable treatment outcome, however they are also associated with some adverse effects in both hard and soft tissue specially in individuals with inadequate oral hygiene, alveolar bone loss,[3] root resorption,[4] white spot lesion[5] and tooth discoloration.[1,6] Fixed orthodontic appliance components such as brackets, tubes, elatstomeric modules etc, acts as nidus of plaque and food debris accumulation thus compromising oral hygiene, which may lead to dental caries and periodontal disease.[7] White spot lesions are common consequence of orthodontic treatment, characterized by chalky white, non-cavitated enamel demineralization. Clinically white spot lesion and plaque accumulation are characterized by loss of natural translucency of tooth due to altered light refraction of discoloration of tooth surface.[8]

Tooth color arises primarily from the scattering of light within the tooth structure, dentin largely dictates the overall color due to its optical density, while enamel contributes minimally, primarily through light scattering at shorter (blue) wavelengths.[9] The final appearance of tooth color is influenced by a combination of intrinsic factors such as the structural and compositional characteristics of dentin and enamel and

extrinsic staining from external agents deposited on the tooth surface or absorbed into dental tissues.[10] Tooth discoloration especially in the upper front (maxillary anterior) region, raising a significant esthetic concern for many dental patients. Dental discoloration can be broadly classified into extrinsic, intrinsic, or combined types. Extrinsic dental stains are defined as discolorations caused by external chromogenic agents that adhere to or accumulate on the outer enamel surface of the teeth. Whereas, intrinsic stains result from the incorporation or deposition of pigmented substances within the dental hard tissues, primarily enamel and dentin. The extent and rate of extrinsic stain accumulation vary significantly among individuals and are influenced by several predisposing factors. Like structural enamel anomalies, variations in salivary composition and flow rate, and suboptimal oral hygiene practices. Additionally, aging is frequently associated with tooth discoloration, which may be attributed to a synergistic effect of long-term exposure to extrinsic staining agents such as coffee, tea, tobacco, and certain medications combined with intrinsic physiological changes in the dental tissues over time.[11]

Color is typically defined using the Munsell color system, which categorizes it into hue, value, and chroma. Hue refers to the optical property that enables the distinction between different color families and is determined by the dominant wavelength range within the visible light spectrum responsible for eliciting a specific color perception. Although the exact wavelength of the perceived hue may not be present, the human visual system interprets a combination of wavelengths, resulting in a subjective physiological and psychological experience of color. Value, or brightness, refers to the quantity of light reflected in an object. According to the Munsell system, value is represented on a grayscale from white to black; objects with higher brightness exhibit

less gray and appear lighter, whereas those with lower value contain grayer and appear darker. Chroma denotes the saturation or intensity of a hue. As chroma increases, value decreases, demonstrating an inverse relationship between chroma and value.[12]

A standardized and accurate approach for quantifying tooth color intraorally is essential for clinical investigations related to tooth discoloration. Visual techniques rely on subjective comparison with shade guides. The most commonly employed approach for tooth color evaluation in clinical dentistry involves visual comparison with standardized color guides. This method entails the simultaneous observation of the natural tooth and the shade guide under consistent lighting conditions.[13] Culpepper highlighted notable inconsistencies among clinicians in their ability to accurately match natural tooth shades, as well as the difficulty some practitioners experience in replicating their own shade selections consistently over time.[14] The growing demand for objective color determination in dentistry, coupled with the rapid advancement of optical-electronic sensors and computer technology, has led to the development of instrumental measurement devices. In evaluating tooth color changes during orthodontic treatment, accurate and reliable shade assessment is critical.[15] The study done by Knezović D et al[16], in 2016 evaluates the reliability of the VITA Easyshade® Advance 4.0, a digital shade-matching device used for dental color assessment. The findings indicate that this spectrophotometer improves accuracy and objectivity in shade determination compared to conventional visual methods. Several studies have evaluated and confirmed that the Vita shade guide is a reliable and validated tool for assessing tooth color.[17-22]

Fixed orthodontic treatment poses significant challenges in maintaining oral hygiene, often leading to plaque accumulation, enamel demineralization, and changes in tooth

color (Ögaard, 1989).[23] The presence of brackets, bands, and archwires creates numerous plaque-retentive areas, making routine cleaning more difficult and increasing the risk of white spot lesions (Gorelick et al., 1982).[24] Additionally, prolonged treatment durations and dietary habits contribute to extrinsic and intrinsic tooth discoloration, which can affect aesthetic outcomes post-treatment (Zachrisson & Årtun, 1979).[25]

Mizrahi et al. (1983)[26] reported increased enamel opacities post-treatment, especially in vestibular areas, emphasizing the need to monitor tooth color and oral hygiene during orthodontic therapy. Monitoring changes in tooth color and oral hygiene status throughout fixed orthodontic treatment is of paramount importance for timely intervention and the implementation of effective preventive strategies. While previous investigations have extensively addressed enamel demineralization and periodontal concerns associated with orthodontic appliances, there remains a notable paucity of clinical research that currently evaluates alterations in both tooth shade and oral hygiene parameters. This observational study seeks to address this critical gap by assessing these changes over the course of fixed orthodontic therapy. The anticipated outcomes will not only offer deeper insight into the esthetic and hygienic implications of orthodontic treatment but will also empower clinicians to adopt more targeted prophylactic protocols, enhance patient compliance through informed education, and ultimately contribute to superior long-term therapeutic outcomes.

Aim & Objectives

AIM AND OBJECTIVES

AIM

"To assess changes in tooth color parameters (Lightness, Chroma, Hue, and ΔE) and oral hygiene status in maxillary anterior teeth (central incisors, lateral incisors, and canines) during fixed orthodontic treatment over a period of six months.".

OBJECTIVES

1. To evaluate longitudinal changes in tooth color parameters Lightness (L), Chroma (C), Hue (h), and overall color difference (ΔE) in maxillary central incisors, lateral incisors, and canines at three time points:

   T0 (baseline, day of bonding)

   T1 (3 months after bonding)

   T2 (6 months after bonding)
2. To determine which of the maxillary anterior teeth (central incisor, lateral incisor, or canine) exhibits the most significant color change during the treatment period.
3. To analyze color changes across different tooth surfaces (mesial, distal, cervical, and incisal) for each maxillary anterior tooth.
4. To evaluate the changes in oral hygiene status between T0, T1, and T2 using an established oral hygiene index.

RESEARCH HYPOTHESIS

Fixed orthodontic treatment causes significant changes in tooth color (L, C, h, E) and oral hygiene status in maxillary anterior teeth over time.

NULL HYPOTHESIS

Fixed orthodontic treatment does not cause significant changes in tooth color (L, C, h, ΔE) or oral hygiene status in maxillary anterior teeth over time

Review of Literature

REVIEW OF LITERATURE

Culpepper WD. (1970)[14] conducted a comparative investigation to evaluate the accuracy and consistency of dental shade-matching techniques among practicing dentists. The study involved 37 dentists of varied specialties and experience levels who were tasked with matching the shades of six natural teeth using four different shade guides and under four lighting conditions. Each participant made 96 shade selections. A follow-up study involving 12 of the original participants tested their ability to replicate two prior shade matches. Results indicated significant inconsistency in shade selection across both studies. The maxillary cuspid was the most consistently matched tooth, but even then, the highest agreement on a single shade reached only 39%. Other teeth exhibited even less consistency. Among shade guides, Bioform yielded the widest range of selections, while Bioblend had the fewest. New Hue offered the highest single-tooth agreement at 41% for the mandibular incisor. Lighting showed no clear superiority, with the highest agreement (51%) under standard and control lighting. In the follow-up, only 22% of shades were duplicated.

Zaghrisson BU& Zachrisson S. (1971)[27] conducted study on Caries incidence and oral hygiene during orthodontic treatment. The study examined 173 individuals undergoing orthodontic treatment and found a clear correlation between oral hygiene and caries incidence. As oral hygiene scores (PI and GI) increased, there was a corresponding rise in caries incidence, indicating that poor oral hygiene can lead to higher rates of caries during orthodontic treatment. The research utilized established indices, such as the Plaque Index (PI) and Gingival Index (GI), to assess oral hygiene. These indices provided a systematic approach to evaluate the presence

of plaque and gingival health, which are critical factors in caries development. The study also noted that different methods

Gorelick L et al. (1982)[24] conducted a study to assess the incidence of white spot lesions (WSLs) associated with different orthodontic appliances, focusing on bonded brackets, bands, and lingual retainers. The aim was to compare the frequency and severity of enamel decalcification among treatment types, with the objective of identifying which appliances pose higher risks for WSL formation. The study involved 302 subjects categorized into four groups: control (no treatment), bonded brackets, bands, and lingual retainers. Clinical and photographic assessments were performed post-treatment. In the bonded bracket group (121 patients), 49.6% exhibited at least one WSL, with 10.8% of 2,211 examined teeth affected particularly maxillary lateral incisors (23%). In the banded group (71 children), 12% of 280 teeth displayed WSLs, while the lingual retainer group (60 patients) showed no decalcification. Results suggested that enamel surfaces exposed to plaque accumulation and difficult-to-clean areas, especially around labial brackets, are more prone to decalcification. The study concluded that labial bonded brackets significantly increase the risk of WSLs compared to other appliances, emphasizing the need for preventive strategies, including improved oral hygiene, dietary control, and topical fluoride application

Maijer R et al. (1982)[28] conducted a clinical and microscopic study to investigate the cause of black and green stains on enamel associated with directly bonded stainless steel orthodontic brackets. The aim was to identify the mechanisms behind these discolorations and suggest preventive measures. Twelve cases showing such

stains were analyzed through intraoral photography and scanning electron microscopy after bracket removal. All brackets were bonded using a conventional acid-etch technique. The analysis revealed voids at the resin-bracket interface and significant corrosion, particularly at the periphery of Type 304 stainless steel mesh bases. Corrosion products, including chromium compounds, were linked to enamel staining, especially in patients with poor oral hygiene. Most stains appeared on maxillary anterior teeth and were often permanent. The study concluded that crevice corrosion, possibly worsened by saliva, plaque, and thermal recycling of brackets, was the primary cause. The authors recommended using more corrosion-resistant stainless steel, such as Type 316L, and maintaining good oral hygiene to minimize staining risk during orthodontic treatment.**Mizrahi E. (1983)[26]** conducted a study on surface distribution of enamel opacities following orthodontic treatment. The study involved 796 patients from a private practice, divided into two groups. Group 1 included 527 pretreatment patients (mean age 11.8 years) with 10,126 teeth. Group 2 comprised 269 post-treatment patients (mean age 15.4 years) with 5,758 teeth. All Group 2 patients underwent comprehensive multiband orthodontic treatment using the Begg light-wire appliance. Opacities were defined as discrete areas of white opaque enamel on tooth surfaces. Scoring system assessed location, extent, and prevalence of opacities on vestibular and lingual surfaces. Each tooth surface was divided into cervical, middle, and incisal thirds for scoring. Severity of opacities was scored from 0 (none) to 3 (full surface area). Maximum score per tooth was 18, with detailed assessment techniques previously described. Higher prevalence of enamel opacities on vestibular surfaces compared to lingual surfaces ($p < 0.001$). Cervical third had significantly higher prevalence than middle and

incisal thirds. Severity of lesions measured by Opacity Index showed similar distribution patterns. Significant differences between Groups 1 and 2 noted only for middle third on vestibular surface ($p < 0.001$). Highest prevalence of opacities found on mandibular and maxillary first permanent molars. Group 2 showed increased prevalence of opacities on middle third of tooth crowns. Significant differences in Opacity Index between Groups 1 and 2 for affected teeth. Findings align with previous studies on enamel opacity distribution in orthodontic patients. Statistically significant increase in enamel opacities post-orthodontic treatment on vestibular and lingual surfaces. Significant increases noted on cervical and middle thirds of maxillary and mandibular first molars. Development of new areas of demineralized enamel attributed to orthodontic treatment.

Øgaard B. (1989)[23] prevalence of white spot lesions in 19-near-olds: A study on untreated and orthodontically treated persons 5 years after treatment. Study conducted on 19-year-old subjects during dental checkups in Raufoss, Norway. Sample included 51 orthodontically treated and 47 untreated individuals. Orthodontic treatment utilized standard edgewise light wire technique; appliances removed after an average of 5.7 years. Study revealed no significant differences in white spot lesions between genders or sides of the mouth. Orthodontic group had significantly higher median white spot scores than untreated group ($p < 0.01$). Only 4% of orthodontically treated patients had no white spot lesions; 15% in untreated group. Most lesions scored 1, indicating less than one-third surface coverage; few scored 2 or 3. Highest prevalence of lesions found on first molars, canines, and premolars in orthodontic group. Lateral incisors more affected than central incisors;

untreated group also showed similar trends.

Van der Burgt et al. (1990)[13] conducted a comparative study was conducted to evaluate the accuracy and reproducibility of three methods for tooth color quantification: the Standards Method, the Fiber-Optics Colorimeter, and the Spectrophotometer Method. The study included 22 extracted human maxillary incisors and 16 acrylic resin incisors, with color measured on the mid cervical labial surface. The Standards Method involved visually matching teeth to 150 opaque color cards from the Sikkens Color Collection under standardized daylight using a grey viewing shield, with results expressed in CIE metrics. The Fiber-Optics Colorimeter Method used a double box to compare the tooth and a white reference surface under adjustable light filters, requiring observer training but offering ease of use. The Spectrophotometer Method used a Zeiss RFC-3 spectrophotometer to capture reflection spectra, converting XYZ tristimulus values to CIELUV coordinates for determining Hue, Value, and Chroma, and provided the most objective and precise measurements. All methods showed acceptable reproducibility, with the Spectrophotometer Method being the most accurate, the Fiber-Optics Colorimeter showing consistent results with proper training, and the Standards Method remaining practical and widely used in clinical practice.

Ten Bosch JJ and Coops JC. (1995)[9] investigated the influence of light scattering and enamel hardness on tooth color, aiming to understand how internal optical properties affect color perception. The objective was to evaluate correlations between enamel hardness, light scattering, and CIELAB color coordinates in extracted human teeth. The study used 102 formalin-fixed human incisors, polished and mounted uniformly. A facet was prepared on each tooth's labial surface for

Knoop hardness testing (500 g load), while reflectance spectra were recorded under illuminants A and D65 using spectroradiometry. Light scattering was assessed using 45°/0° and 0°/0° geometries. The average color values were L = 69.9, a = 1.22, and b = 17.9. Results showed a moderate correlation between L and enamel scattering (r = 0.60), a negative correlation between L and a (r = -0.51), and a weak but significant correlation between hardness and L (r = 0.17, p = 0.03). Mean enamel and dentin scattering coefficients were both 0.6 mm^{-1}, and average hardness was 271 kg/mm^2. The study concluded that enamel and dentin light scattering are key determinants of tooth color, while enamel hardness has a lesser impact. Notably, dentin remained a significant contributor to tooth color even after enamel removal, and fluorescence showed no effect, underlining the dominance of structural optics in shade analysis. These findings emphasized the importance of considering both enamel and dentin optical properties in restorative dentistry, especially in shade matching procedures for aesthetic treatments. Understanding the role of scattering can aid in developing more accurate color-matching techniques and material selection in prosthodontics and cosmetic dentistry.

Joiner A et al. (1995)[19] conducted a detailed in situ study to assess the influence of various factors on extrinsic tooth stain formation. Eighteen participants wearing upper dentures were recruited, and enamel specimens categorized as either rough or smooth were embedded in the buccal flanges of their dentures. The enamel inserts, derived from bovine teeth, underwent standardized surface preparation and sterilization prior to placement. The study aimed to simulate real-life oral conditions while minimizing artificial constraints. Participants followed a consistent denture-cleaning routine using a standard dentifrice and toothbrush, with the instruction not

to brush directly over the inserts. No dietary or lifestyle restrictions were imposed, allowing for a natural assessment of stain accumulation. Color changes of the enamel blocks were monitored over a 28-day period using a Minolta CR-321 Chroma Meter, applying the CIELAB color system (L, a, b), with changes in overall color (ΔE), lightness (ΔL), hue angle (h), and chroma (ΔC) recorded and analyzed. The results showed the most significant color changes occurred within the first seven days, especially a shift in hue from blue to yellow and a gradual increase in chroma over time. Interestingly, while the data showed no consistent trend favoring rough or smooth inserts in terms of staining, in some cases, rough inserts exhibited higher chroma changes. Moreover, smoking appeared to correlate strongly with greater staining (higher SAC values), while consumption of tea, coffee, alcohol, or iron supplements did not show a significant relationship. This study effectively highlighted the multifactorial nature of stain formation, pointing to surface texture and lifestyle especially smoking as influential factors. The in-situ model allowed for a clinically relevant simulation of oral conditions, offering valuable insights for preventive and cosmetic dentistry.

Hodges SJ et al. (2000)[29] two clinical cases of unusual, persistent enamel staining after fixed orthodontic therapy in patients with pre-existing enamel defects (hypomineralization and amelogenesis imperfecta). In the first case, a green-black stain appeared beneath a bracket on a hypomineralized central incisor despite standard bonding, with bond failures and chemically-cured composite possibly contributing. The stain could not be removed through polishing, but microabrasion and bleaching helped, and porcelain veneers provided a satisfactory result. The second case involved red-brown staining under anterior bands in a patient with hypo-

mature amelogenesis imperfecta, with staining more pronounced after shorter band placements. Microabrasion slightly reduced the discoloration, and porcelain veneers offered an aesthetic solution. Contributing factors included enamel porosity, crevice corrosion at the bracket-resin interface, and corrosion products from stainless steel attachments. The stains were linked to chromium and iron oxides. The review recommends preventive strategies like monitoring corrosion, using corrosion-resistant materials, and considering non-metallic options for patients with enamel defects to avoid permanent aesthetic damage.

Eliades T et al. (2001)[30] aimed to evaluate the enamel color changes associated with orthodontic bracket bonding using two different adhesives: a no-mix (one-phase) adhesive resin (Unite) and a glass-ionomer adhesive (GC Fuji Ortho). The study involved 30 recently extracted premolars, with each tooth divided into two groups of 15. Brackets (Starfire TMB) were bonded using the two adhesives, and the enamel color was assessed at three-time intervals: before bonding (baseline), after debonding and cleaning, and following artificial photo-ageing for 24 hours. Enamel color changes were measured using the CIE L, a, b parameters, and ΔE values were calculated for each interval. The results were analyzed statistically using two-way repeated measures ANOVA and Scheffé's multiple range test. Significant color differences were observed, particularly between the baseline and debonding stages for both adhesives, with all changes exceeding the threshold for clinical detection ($\Delta E > 3.7$). No significant difference was found between etching-mediated and no etching-mediated bonding, suggesting that the debonding and cleaning process, particularly adhesive grinding, may cause more invasive enamel color changes than acid etching.

Joiner A. (2004)[10] reviewed the factors influencing tooth colour and the methods used for its assessment. Tooth colour is influenced by both intrinsic and extrinsic factors. Intrinsically, it is determined by light absorption and scattering within enamel and dentin, with dentin playing the dominant role in colour perception and enamel contributing mainly in the blue spectrum. Extrinsic discolouration, on the other hand, results from surface staining due to substances like tea, coffee, wine, and certain mouthrinses. Various methods are used to assess tooth colour, including visual and instrumental techniques. Visual shade matching with guides is common in clinical practice but is prone to subjectivity due to lighting conditions, operator variability, and inconsistent shade distribution. Instrumental methods, such as spectrophotometry and colourimetry, offer more accurate and reproducible results. Spectrophotometers provide detailed spectral data but are complex and costly, whereas colourimeters are more practical for routine use, despite limitations in measuring curved surfaces and differences between devices. Conventional shade guides often fail to represent the full spectrum of natural tooth colours and lack standardization. Improved systems like the 3D-Master guide have enhanced repeatability and colour range coverage. Tooth colour perception is also affected by surrounding oral tissues and individual aesthetic expectations, with many patients associating lighter shades with cleanliness and beauty. Despite technological advancements, visual evaluation remains central in clinical settings. The need for reliable, standardized, and practical methods of assessing tooth colour is essential, particularly in the context of increasing demand for aesthetic treatments like tooth whitening.

Lovrov S et al. (2007)[31] conducted a study on enamel demineralization during fixed

orthodontic treatment-incidence and correlation to various oral-hygiene parameters. This study aimed to investigate the incidence of white spot lesions (WSLs) around brackets and molar bands during orthodontic therapy and determine whether a correlation with dental and gingival health indices, fluoride application, and oral hygiene could be established. Fifty-three patients with fixed orthodontic appliances were randomly selected from the Department of Orthodontics at Erlangen-Nuremberg University. Dental health (DMFS), plaque index, papillary bleeding index, sulcus probing depth (SPD), gingival recession (GR), clinical attachment level (CAL), oral hygiene, and fluoride use were assessed. WSLs were graded based on intraoral photographs taken before and after treatment. This study shows that prior to treatment, 97.5% of teeth were free of WSLs, decreasing to 73.6% after treatment. Approximately 24.9% of teeth developed new WSLs or an increase in their number. WSL incidence was more common in upper and lower premolars (34.4%) and front teeth (28.1%) compared to molars (11.8%). The occurrence of WSLs during therapy correlated with the clinical attachment level, as well as the scores for oral hygiene and fluoride use. This study concludes that, orthodontic treatment can result in significant risk of enamel demineralization. Prophylactic efforts by patients, including the use of fluoride, play a crucial role in preventing WSLs.

Derdilopoulou et al. (2007)[32] conducted a clinical comparison of 3,758 teeth for evaluation of visual and spectrophotometric shade analyses. The objective of this study was to assess the performance of visual and spectrophotometric tooth shade analysis. Two operators independently evaluated the shade match of 3,758 anterior teeth from 106 patients on three different occasions using the Chromascop-Complete

shade guide. In addition, the tooth color was measured three times consecutively using a reflectance spectrophotometer. The results showed a high level of agreement in spectrophotometry, with 89.6% of measurements demonstrating consistency. Both examiners agreed on the shade selection in 49.7% of the cases. However, visual assessment resulted in significantly darker ratings compared to spectrophotometry. Nonetheless, there was a positive association observed between both methods. These findings suggest that spectrophotometric shade determination is significantly more reproducible than the visual procedure. Spectrophotometry provides consistent results and minimizes variations between operators.

Wriedt S et al. (2008)[33] conducted an in-vitro study to assess the influence of bonding, debonding, and bleaching on enamel color. The aim was to determine whether these procedures, alone or in combination, result in significant color changes in tooth enamel. Ninety bovine lower incisor crowns were divided into nine subgroups based on three bonding materials (chemical-cured, light-cured, and pressure-cured) and three bleaching agents (15 percent carbamide peroxide, 35 percent carbamide peroxide, and 38 percent hydrogen peroxide). Each tooth was segmented into four zones: untreated, bleached only, bonded-debonded only, and bleached after bonding-debonding. CIELCh color values were recorded using a spectrophotometer, and Delta E values were calculated to determine color differences. Visual evaluations were also performed by two orthodontists and two dentists. Statistical analysis included the sign test, Wilcoxon test, Kruskal-Walli's test, and Mann-Whitney U test. Results indicated significant color differences between bleached and non-bleached areas ($p < 0.05$), but no significant differences due to bonding or debonding procedures, nor between areas bleached before or after

debonding ($p > 0.05$). The study concluded that bonding and debonding do not significantly affect enamel color, and bleaching after these procedures does not increase color alteration.

Kim-Pusateri S et al. (2009)[34] conducted a study to evaluate reliability and accuracy of four dental shade-matching devices. The SpectroShade, ShadeVision, VITA Easyshade, and ShadeScan shade-matching devices were tested. Three commercial shade guides Vitapan Classical, Vitapan 3D-Master, and Chromascop were used to measure colour. Shade tabs of the same nominal shade from extra shade guides were positioned on both sides of a gingival matrix (Shofu GUMY), with shade tabs in the center of the matrix. The shade tab's middle portion, which was located inside a black box, was measured. Each shade tab from each of the three types of shade guides was measured ten times for the reliability assessment. Each shade tab from 10 guides of each of the three examined types was measured once for the accuracy evaluation. The Standard Normal z test (2-sidedsided) was used to assess differences in reliability and accuracy. Result of the study shows that VITA Easyshade offers 96.9% reliability accuracy of devices, which is the highest of the other 4 devices up to 92.6% and 96.9% reliability.

Trakyali G et al. (2009)[35] conducted a study to assess enamel color changes associated with five different orthodontic bonding adhesives after debonding and finishing procedures, followed by artificial photoageing. The study included 75 non-carious premolars randomly assigned to five groups, with each group bonded using one of the following adhesives: Transbond XT, Eagle Bond, Light Bond, Blugloo, and Unite. Enamel color was measured at four stages: pre-bonding, post-debonding and cleaning with a tungsten carbide bur, post-polishing with Stainbuster, and after

24 hours of artificial accelerated photoageing. The CIE L, a, b system was used to quantify enamel color, and ΔE values were calculated. Data were statistically analyzed using the Kruskal-Walli's test, with Dunn's multiple correlation test applied for subgroup comparisons at a significance level of $P < 0.05$. Results indicated increased ΔE values between pre-bonding and post-cleaning measurements in the Transbond XT, Eagle Bond, and Light Bond groups, with the highest value of 1.51 ± 1.15 in the Transbond XT group. However, all color changes remained below the clinical perceptibility threshold of $\Delta E = 3.7$. The study concluded that discoloration from orthodontic adhesives after photoageing is not clinically detectable and that polishing with Stainbuster effectively smooths enamel surfaces, potentially enhancing light reflection and minimizing visible color changes.

Karamouzos A et al. (2010)[36] conducted a prospective in-vivo study to evaluate color changes in natural teeth associated with fixed orthodontic treatment. The aim was to investigate how the use of different adhesive systems chemically cured and light-cured resins affects tooth color over time. Twenty-six patients were included, each receiving a split-mouth design treatment with both adhesive types used for bracket bonding. Spectrophotometric measurements were taken on a standardized labial circular area of each tooth before bracket placement and after bracket removal and cleaning. Tooth color was recorded using Commission Internationale de l'Eclairage parameters L for lightness, a for red-green spectrum, and b for blue-yellow spectrum, and the overall color difference ΔE was calculated. Statistical analysis was performed using three-way mixed ANOVA and Bonferroni comparison tests with a significance level set at alpha less than 0.05. The results showed that L

values significantly decreased while a and b values increased, indicating teeth became darker and shifted slightly toward red and yellow tones. All tooth types demonstrated significant color changes with ΔE values ranging from 2.12 to 3.61, and chemically cured resin resulted in greater discoloration than light-cured resin. In conclusion, the study confirmed that fixed orthodontic appliances can cause perceptible changes in natural tooth color, with the extent of alteration influenced by the type of adhesive used.

Llena C et al. (2011)[20] conducted a study to evaluate the reliability of two commonly used dental spectrophotometers EasyShade (ES) and SpectroShade Micro (SSM) in measuring and matching tooth colour. The objective was to assess both intra-device (repeatability) and inter-device consistency in obtaining L, a, b values, as well as shade matches to the VITA Classical and Vitapan 3D-Master shade guides. Tooth colour was measured on six maxillary and mandibular teeth. Colour coordinates (L, a, b) and shade matches were recorded for each device. The colour difference (ΔE) was also calculated to compare the outcomes of the two systems. Statistical analysis was performed using paired t-tests and intraclass correlation coefficients (ICC) to evaluate consistency and agreement. The results showed no significant intra-device differences ($p > 0.05$) in L, a, and b values for either system, indicating good repeatability. However, when comparing between devices, significant differences were found: L and b values were higher with ES, while values were higher with SSM ($p < 0.05$). Despite these variations, ΔE values did not show significant differences between the two devices. The ICC values were slightly higher for ES, suggesting better, though not statistically significant, repeatability. The study accepted the hypothesis that both devices showed no significant variation within themselves but

rejected the hypothesis of equivalency between the two devices. This indicates that while both ES and SSM are reliable individually, they are not directly interchangeable due to measurable differences in output. In conclusion, both spectrophotometers demonstrated excellent repeatability, making them suitable for clinical use in evaluating tooth colour and monitoring colour changes after treatment. Their application in practice supports a more objective and standardized approach to colour diagnosis and aesthetic dental procedures.

Atassi F and Awartani F. (2011)[37] conducted a study on oral hygiene status among orthodontic patients. This study was conducted on 50 patients aged between 15-30 years in which 32 patients were males and 28 patients were female. Aim of the study measure the oral hygiene status among patients with fixed orthodontic appliances oral hygiene of patients examined using orthodontic plaque index (OPI), plaque index (PI) and gingival bleeding index (GBI) and according to this formula [(Number of bleeding sites)/ (Number of examined sites) 100], the degree of gingivitis was determined. A thorough questionnaire created for all patients was used to gather data about the patient's dental hygiene routines performed during orthodontic treatment. The questionnaire asked about the patients' diet during treatment, how often they saw a dental hygienist, and whether or not they used a toothbrush, how often they used it, and whether or not they used any other oral hygiene products like floss or mouthwash. Result of this study shows Orthodontic plaque index shows 20 (40%) patients had fair oral hygiene and 30 (60%) patients had poor oral hygiene.

Cantekin K et al. (2011)[38] conducted a comprehensive study-effects of orthodontic

treatment with fixed appliances on oral health status. The goal study was to evaluate changes in the oral health condition in a sample of young Turkish dental patients who were receiving orthodontic treatment. There were 659 patients included in study, who ranged in age from 12 to 16. Oral health status was evaluated using missing, and filled permanent teeth (DMFT) counts and plaque index (PI). Wilcoxon and Manne-Whitney U tests were used in the data analysis. The findings showed an increase in DMFT counts and the plaque index (PI) in a group of young dental patients receiving orthodontic treatment and the PI revealed minimal values at the start of orthodontic treatment and maximal levels at the completion of treatment. This study's concluded that among a group of young dental patients receiving orthodontic treatment, DMFT counts and the PI increased.

Beberhold K et al. (2012)[39] introduced the Orthodontic Plaque Index (OPI), an oral hygiene tool specifically designed for patients with multibracket appliances. The OPI assesses both plaque accumulation and the condition of the adjacent marginal gingivae, helping to evaluate oral hygiene, caries, and gingivitis risks while identifying areas in need of preventive measures to minimize the risk of demineralization and gingivitis. The index uses a plaque-disclosing solution, such as erythrosine, which stains the plaque on teeth with bonded brackets (excluding bands). The dentition is divided into sextants, and the highest score per sextant is recorded. The scoring system ranges from 0 to 4, where a score of 0 indicates no plaque, 1 indicates plaque on one surface, 2 on two surfaces, 3 on three surfaces, and 4 on four surfaces or signs of gingival inflammation. In addition, the index evaluates gingival condition to help determine the need for further prophylactic treatment. The OPI scores guide oral hygiene assessments, with scores of 0 and 1 indicating very

good to good oral hygiene, a score of 3 indicating mediocre hygiene, and scores of 3 and 4 suggesting inadequate oral hygiene, prompting the need for increased attention to preventive care and improvement in cleaning techniques.

Zaher AR et al. (2012)[40] conducted an in vitro study to investigate the relationship between enamel color changes and resin tag depth following orthodontic bracket debonding. Fifty freshly extracted human premolars were randomly assigned to a control group and four experimental groups. Group I received enamel prophylaxis only, while groups II and III were etched with 35% phosphoric acid for 15 and 60 seconds, respectively. Groups IV and V were treated with Prompt L-pop and Xeno III self-etching primers. All experimental teeth had brackets bonded with Transbond XT and underwent debonding, finishing, and polishing. Enamel color was measured spectrophotometrically before bonding and after debonding, with ΔE values calculated to quantify color change. Resin tag lengths were assessed via scanning electron microscopy. Results showed that all experimental groups exhibited ΔE values exceeding the clinical perceptibility threshold of 3.7, indicating visible color changes. Statistically significant differences in resin tag lengths were observed across groups, and a moderate positive correlation was found between tag length and enamel discoloration. The study concluded that reduced resin penetration, as achieved with self-etch primers, may lead to less enamel color alteration following orthodontic treatment, suggesting that shallower resin tags are associated with diminished aesthetic impact post-debonding.

Al Maaitah EF et al. (2013)[41] conducted a clinical study evaluated the effect of different etching techniques on tooth color during fixed orthodontic treatment. Thirty-four patients were divided into two age groups: adolescents (17 or younger)

and adults (above 17 years). The color of anterior teeth in both the maxillary and mandibular arches was measured before bonding and after debonding using a Vita Easyshade Compact spectrophotometer. Two etching techniques were used: self-etching primer and conventional acid etching, with random allocation in a split-mouth design. Tooth color was measured based on the Commission International de l'Eclairage system, assessing lightness (L), red/green (a), and yellow/blue (b) parameters. Significant changes in all color parameters were observed ($P < 0.05$), with a decrease in lightness by 2.16 units, and increases in red/green and yellow/blue values by 0.32 and 1.78 units, respectively. The average tooth color difference was 2.85 units. No significant difference was found between the etching techniques ($P > 0.05$). Men and adolescents experienced greater color changes compared to girls and adults ($P < 0.05$). In conclusion, fixed orthodontic appliances caused noticeable tooth color changes, with no significant difference between etching techniques. Men and adolescents showed greater color changes than girls and adults. The study highlights the importance of considering demographic factors and etching techniques when planning orthodontic treatment to manage potential aesthetic changes.

Boncuk Y et al. (2014)[42] investigated the effect of different orthodontic adhesives and resin-removal techniques on enamel color changes after bracket debonding. The study aimed to assess how etch-and-rinse adhesive, self-etch primer (SEP), and resin-modified glass ionomer cement (RMGIC), combined with either tungsten carbide or Stainbuster burs, affect enamel discoloration. Metal brackets were bonded to 175 extracted premolars, photoaged for 24 hours, debonded, and cleaned with one of the two burs. Spectrophotometric color measurements were taken at baseline, post-cleaning, and after further photoaging. Statistical analysis was performed using

Kruskal-Wallis and Mann-Whitney U-tests with Bonferroni correction. Results showed all groups experienced color changes, with the highest discoloration in the etch-and-rinse/tungsten carbide group. The Stainbuster bur significantly reduced color change when used with etch-and-rinse or SEP adhesives, while bur type had no impact in the RMGIC group. The study concluded that both adhesive type and resin-removal method influence enamel color, recommending Stainbuster burs for minimal discoloration with resin adhesives.

Knezović D et al. (2015)[16] conducted a study in which vitro and in vivo models were used in this study to assess the intra-device repeatability and accuracy of the dental shade-matching device (VITA Easyshade® Advance 4.0). The in vivo study model central portion of the labial surface of right maxillary central incisors of 10 patients was measured twice and the six Vitapan Classical tabs were used in the in vitro model; the middle portion of each shade tab was measured twice using the VITA Easyshade® Advance 4.0. Result of studyshows that differences in the mean values of measured colors between in vivo and in vitro measurements were found to be 3.51 E and 1.25 E units, respectively. These differences indicate variations in tooth color measurements depending on whether they were measured in vivo (within the patient's mouth) or in vitro (outside the mouth). The coefficients of repeatability (ICC) for the in vivo measurements ranged from 0.858 to 0.971, indicating good consistency and reliability of the measurements within the in vivo setting. For the in vitro measurements, the ICC values ranged from 0.992 to 0.994, demonstrating even higher levels of repeatability and consistency. The accuracy of the tested device was reported to be 93.75 percent. This indicates that the VITA Easyshade®Advance 4.0 tooth color determination device provided measurements that were highly accurate,

with a relatively low margin of error. The study concluded that VITA Easyshade®Advance 4.0 tooth color determination device proved to be a reliable and precise tool for assessing tooth color. Its high accuracy and consistent repeatability make it a valuable instrument for determining tooth color in both clinical and laboratory settings.

Chen Q et al. (2015)[43] performed a systematic review to assess whether fixed orthodontic appliances affect enamel color, focusing on the influence of bonding agents and resin removal techniques. While enamel surface changes from orthodontic treatment are well-documented, color changes had not previously been systematically reviewed. Following PRISMA and Cochrane guidelines, five studies were selected from 1410 identified references three randomized controlled trials and two prospective studies. Most studies focused on the impact of different orthodontic adhesives. Chemically cured adhesives generally caused greater enamel color changes than light-cured adhesives, with some changes exceeding the ΔE threshold for clinical detection, though often not visually noticeable. One study found significant enamel color changes between bonding and debonding stages, regardless of adhesive type. Resin removal methods were also assessed. Instruments like the Stain buster bur resulted in smoother enamel surfaces and less visible discoloration compared to traditional burs. However, these findings were mostly from in vitro studies, limiting their relevance in real-world conditions. The review concluded that orthodontic adhesives and resin removal methods can influence enamel colour, but current evidence is limited due to methodological weaknesses. Better-designed clinical trials are needed to confirm these findings and determine their clinical importance.

Cörekçi B et al. (2015)[44] conducted a controlled clinical study evaluated the effect of various contemporary orthodontic composite adhesives on tooth color following short-term fixed orthodontic treatment. The study included 22 treated patients and 22 untreated controls. In the treated group, lower incisors were bonded using four orthodontic composites: Grengloo, Light Bond, Kurasper F, and Transbond XT. Tooth color was measured using a spectrophotometer and assessed based on the CIE L, a, and b color coordinates. Statistical analysis showed that fixed appliance treatment affected tooth color, with increased L (lightness) and a (red-green) values, and decreased b (yellow-blue) values, indicating brighter, less yellow teeth. The total color differences (ΔE) ranged from 1.12 to 3.34 units, which are clinically perceptible. However, no significant differences were found between the adhesives, suggesting similar discoloration potential for all tested composites. The study concluded that short-term orthodontic treatment may cause visible tooth color changes, but the choice of composite adhesive does not significantly affect the degree of discoloration, implying that enamel discoloration during orthodontic treatment is more likely linked to the treatment process itself rather than to the specific adhesive used.

Anuwongnukroh N et al. (2017)[45] conducted a study to evaluate oral hygiene behavior among 105 patients (33 males and 72 females) undergoing fixed orthodontic treatment. Participants completed a questionnaire covering reasons for seeking treatment, its perceived necessity in daily life, and oral hygiene practices after appliance placement. Most patients (83%) sought treatment for esthetic tooth alignment, and 85.7% considered it necessary in their daily life. During treatment, 61% used an orthodontic toothbrush and 81.9% used fluoride toothpaste. Dental

floss was used regularly by 19% and occasionally by 60%, while mouthwash was used regularly by 23.8% and occasionally by 55.2%. Toothpicks were used regularly by 21% and occasionally by 51.4%, and interdental brushes were used regularly by 36.2% and occasionally by 51.4%. Regarding brushing habits, 45% brushed in the morning and before bed, 28.6% after meals, and 25.7% after every meal or snack. Although 83% received brushing instructions from orthodontists or dental assistants, only 52.4% were given advice on oral hygiene care supplements. In conclusion, while most patients understood the importance of orthodontic treatment and regularly used fluoride toothpaste, there remains a need for more comprehensive oral hygiene education, including the proper use of oral hygiene adjuncts, to help prevent dental caries and periodontal disease during fixed orthodontic treatment.

Kamber R et al. (2017)[1] conducted a systematic review and meta-analysis was conducted to determine whether fixed orthodontic treatment has a lasting effect on tooth color. The review included clinical cohort studies assessing color changes after treatment, with data sourced from nine databases up to May 2017. Four studies met the inclusion criteria three nonrandomized and one randomized covering 138 patients with a mean age of 15.7 years. The results showed that orthodontic treatment was associated with a measurable change in tooth color, with an average difference of 3.2 ΔE units (95% CI: 2.0–4.4), which exceeds the threshold for perceptible color change. In contrast, control groups showed a smaller change of 1.9 ΔE units (95% CI: 1.7–2.2). However, the overall quality of evidence was rated very low according to GRADE criteria due to the limited number of studies, small sample sizes, and the use of mostly nonrandomized designs. The review also found that color changes varied by adhesive type (chemical vs. light-cured) and by tooth category, suggesting

that bonding materials and tooth anatomy may affect discoloration. Despite these findings, the authors emphasized that the current evidence is not strong enough to make firm clinical recommendations, and they called for more high-quality randomized trials to better understand the impact of fixed appliances on tooth color and the influence of bonding agents and tooth type on esthetic outcomes.

Vatsala V et al. (2017)[46] carried out an in vitro study to examine enamel color changes associated with bonding and debonding procedures during fixed orthodontic treatment and to compare the effects of common staining agents tea, coffee, and turmeric on these changes. A total of 100 freshly extracted premolars were randomly divided into four groups of 25 teeth each. Group 1 served as the control and was stored in distilled water, while Groups 2, 3, and 4 were immersed in tea, coffee, and turmeric solutions, respectively, for seven days following the debonding procedure. To evaluate color changes, the researchers used the X-Rite i1Pro reflectance spectrophotometer and recorded values according to the CIE Lab color system. Measurements were taken before bonding and after debonding and polishing. The color difference (ΔE) was calculated to determine the extent of visible enamel color change. All groups exhibited ΔE values greater than 3.7, indicating that the color changes were perceptible to the human eye. Coffee-stained teeth demonstrated the greatest change (ΔE = 12.46), while the distilled water group showed the least (ΔE = 9.71). Despite numerical differences, statistical analysis using ANOVA revealed no significant differences in ΔE values between the groups ($p > 0.05$). Changes in L, a, and b values showed that enamel darkened (decreased L), shifted towards green (lower a), and became more yellow (increased b) after debonding. These shifts align with existing literature that links enamel roughness post-orthodontic treatment with

increased susceptibility to staining. The findings suggest that enamel discoloration occurs as a result of bonding and resin removal procedures, regardless of the staining solution. Although the degree of staining varied slightly with each agent, the effects were comparable across groups. The study emphasizes the importance of careful polishing techniques and post-treatment enamel care to reduce aesthetic compromises after orthodontic therapy.

Mahindra RK et al. (2017)[47] conducted a study to evaluate the effects of fixed orthodontic treatment on gingival health. The primary aim was to assess the periodontal status in patients undergoing fixed mechanotherapy and to highlight the importance of maintaining oral hygiene during orthodontic treatment. The objective was to observe the impact of fixed appliances on plaque accumulation and gingival inflammation using established clinical indices. A total of 30 orthodontic patients aged between 15 and 30 years, all undergoing full-mouth fixed orthodontic therapy, were selected for this observational study. Patients with systemic conditions, recent antibiotic use, or poor compliance were excluded. Data collection involved clinical assessment of oral hygiene using the Plaque Index (PI), Gingival Bleeding Index (GBI), and Orthodontic Plaque Index (OPI), complemented by a validated questionnaire covering oral hygiene practices, brushing methods, adjunct aids, and dietary habits. Results showed that patients had elevated plaque and gingival scores, with mean PI, GBI, and OPI values of 65.24, 19.14, and 53.56 respectively. Most participants demonstrated inadequate oral hygiene practices despite regular brushing, and only a minority used interdental aids or visited dental hygienists. The study concluded that fixed orthodontic appliances significantly influence gingival health by increasing plaque retention, thereby necessitating consistent oral hygiene

education and motivation to prevent periodontal complications during orthodontic treatment.

Pandian A et al. (2017)[48] conducted a literature review to assess and compare the impact of various orthodontic bonding systems and clean-up procedures on quantitative enamel color changes. The objective was to determine how different adhesives and clinical techniques influence the degree of enamel discoloration after orthodontic treatment. A systematic search was performed using PubMed, Cochrane, and Google Scholar databases. The first stage involved screening abstracts based on predefined inclusion criteria, followed by full-text analysis in the second stage. Bibliographies of selected articles were also reviewed to identify additional relevant studies. Out of sixteen full-text articles, ten met the eligibility criteria and were included in the final analysis. The review found that orthodontic bonding, debonding, and subsequent clean-up procedures significantly affect enamel color. It was noted that self-etching primers resulted in less discoloration compared to conventional acid etching, and resin-modified glass ionomer cement (GIC) showed the least color change among all adhesive types, including light-cure and chemical-cure systems. Additionally, the study concluded that polishing after clean-up procedures plays a crucial role in minimizing enamel discoloration, highlighting the importance of adhesive selection and finishing technique in preserving post-treatment aesthetics.

Pinto AS et al. (2017).[49] evaluated the impact of the duration of fixed orthodontic treatment on gingival enlargement, with a specific focus on plaque accumulation, in adolescents and young adults. The objective was to determine whether longer treatment periods lead to higher plaque index and contribute to gingival changes.

The study involved 260 participants aged 10 to 30 years, categorized into four groups: individuals without orthodontic appliances, and those undergoing treatment for one, two, or three years. Participants completed questionnaires about oral hygiene habits, and clinical examinations were conducted to assess plaque index, gingival index, and gingival enlargement using standardized measures. Results demonstrated a progressive increase in plaque index from individuals without treatment to those treated for one and two years, with no significant increase observed between the second and third years of treatment. Statistical analysis using Poisson regression showed a markedly increased risk of gingival enlargement with longer treatment durations. The authors concluded that prolonged orthodontic treatment is associated with higher plaque accumulation, emphasizing the importance of continuous oral hygiene reinforcement throughout the course of orthodontic therapy.

Kaya Y et al. (2018)[50] conducted a long-term clinical study to evaluate enamel color changes following fixed orthodontic treatment. The study included 120 maxillary central and lateral incisors and canines from 20 patients, with tooth color measured using a Spectro Shade Micro spectrophotometer at four time points: immediately after treatment, and at 3 months, 6 months, and 1 year into retention. The Commission Internationale de l'Eclairage (CIE) L, a, and b system was used to track changes in lightness (L), red-green (a), and yellow-blue (b) values, and color differences (ΔE) were calculated. Results showed a significant increase in lightness (ΔL) during the first 3 months, while changes from month 3 to 6 and from month 3 to 1 year were not statistically significant. Changes in Δa and Δb were also not significant, but ΔE values showed statistically significant differences at all intervals, with the highest change seen at 1 year. ΔE values ranged from 1.52 to 3.57,

indicating that although enamel color changes were noticeable, they stayed within clinically acceptable limits. The study concluded that fixed orthodontic treatment can cause mild but visible changes in enamel color, especially in lightness, mainly occurring in the first three months after treatment, underlining the need to monitor aesthetic outcomes even during the retention phase.

Ratzmann A et al. (2018)[51] conducted a clinical study to evaluate the effect of multibracket appliance treatment on tooth color. The aim was to determine whether fixed orthodontic treatment leads to clinically significant changes in enamel coloration. Fifteen patients undergoing multibracket appliance treatment had the color of their teeth numbered 14 to 24 assessed in both the body and gingival regions using the Shade Inspector spectrophotometer. Measurements were taken at three time points: before treatment (T0), at the end of treatment after approximately two years (T1), and three months post-treatment (T2). Both two-dimensional and three-dimensional color systems were used to quantify changes, and multilevel models were employed for statistical analysis to evaluate intra-segmental changes and differences between regions. The results showed that the maximum color change observed was 2.0 Delta E units in the gingival segment and 2.3 Delta E units in the body segment, both below the clinical threshold of 2.7 Delta E units. Confidence intervals indicated no significant differences in color change between body and gingival areas. The study concluded that multibracket appliance treatment does not result in clinically relevant changes in tooth color, affirming its safety regarding esthetic outcomes.

Kumar A et al. (2021)[52] conducted a clinical study to evaluate oral health status

with a particular focus on plaque accumulation in patients undergoing fixed orthodontic treatment. The objective was to monitor changes in plaque index over time in adolescents receiving treatment. A total of 168 patients aged 12–17 years were assessed over a two-year period. Plaque levels were measured at three intervals initial visit, after one month, and at the end of treatment using the modified Silness and Loe plaque index. All patients were given standardized oral hygiene instructions, including the modified Bass brushing technique with fluoridated toothpaste twice daily, the use of mouthwash once daily, and dietary advice to reduce sugar intake. Results revealed an initial decrease in mean plaque index from 1.06 at the first visit to 1.00 at the second, followed by a significant increase to 1.40 at the end of treatment. This trend suggests that although short-term oral hygiene compliance may be achieved, long-term plaque control often deteriorates during orthodontic treatment. The study concluded that fixed appliances contribute to increased plaque retention over time, emphasizing the importance of sustained oral hygiene reinforcement and regular professional supervision throughout the orthodontic therapy.

Kumar V et al. (2021)[53] conducted observational study to assess the impact of fixed orthodontic treatment on gingival health, recognizing that fixed appliances disrupt natural oral self-cleansing and make oral hygiene more difficult, leading to increased plaque accumulation and gingival problems. The study involved 120 patients undergoing fixed orthodontic therapy, with clinical data collected through intraoral and extraoral radiographs, photographic records, and thorough intraoral examinations. Key parameters assessed before and after treatment included visible plaque levels, gingival inflammation, gingival recession, and gingival biotype,

which was evaluated based on gingival texture and capillary visibility. The results showed a significant decline in gingival health after treatment. The mean visible plaque index increased from 3.11 to 5.81, and gingival inflammation rose sharply from 2.89 to 15.43. The gingival recession scores also increased from 0.19 to 0.383, with all changes being statistically significant. Additionally, there was a shift in gingival biotype, with more patients showing thick biotypes and fewer with thin biotypes in both arches. The study concluded that fixed orthodontic appliances lead to a significant increase in plaque retention, gingival inflammation, and recession, highlighting the importance of regular oral prophylaxis and reinforced oral hygiene during treatment to prevent periodontal issues and maintain gingival health.

Yildiz T et al. (2021)[54] conducted a retrospective study to assess the impact of orthodontic treatment on visible dental plaque, gingival recession, and white spot lesions (WSLs). The study included 170 patients (86 females and 84 males) who were evaluated using pre-treatment and post-treatment oral photographs. Maxillary and mandibular incisors, canines, first and second premolars, and first molars were examined, excluding previously extracted teeth. The study found a significant increase in visible dental plaque from pre-treatment (T0) to post-treatment (T1) ($P < 0.001$), suggesting that orthodontic appliances contribute to plaque accumulation due to their complexity. In contrast, no significant change was observed in the distribution of gingival recession according to the Miller classification before and after treatment ($P = 0.082$). A significant rise in the severity of WSLs was detected between the two time points ($P < 0.001$), with males showing a higher incidence of WSLs after treatment. This indicates that orthodontic treatment can lead to enamel demineralization, particularly in male patients. In conclusion, the study

demonstrated a significant increase in visible dental plaque and white spot lesions following orthodontic treatment.

Santos LLD et al. (2021)[55] conducted a clinical study aimed at evaluating color change (ΔE) and luminosity (L) of dental enamel surfaces after orthodontic treatment, specifically around the areas where brackets were bonded. The objective was to assess the esthetic outcomes associated with two different adhesive materials: a composite resin (R group) and a resin-modified glass ionomer cement (RMGIC group). This split-mouth study initially included 14 patients, with brackets bonded to the upper central incisors using either of the two materials. Spectrophotometric and visual assessments of enamel color were performed prior to bracket placement and after 12 months of orthodontic treatment, at which point the brackets were removed. Due to dropouts, only 10 patients completed the study. The Adhesive Remnant Index (ARI) was recorded after debonding, while ΔE values were analyzed using Student's t-test and L values through repeated-measures ANOVA, with statistical significance set at $\alpha=0.05$. The findings revealed a statistically significant difference in ΔE between the groups, with the RMGIC group demonstrating less color change, suggesting better color stability. The resin group exhibited higher L values, indicating increased brightness of the enamel surrounding the brackets. ARI scores of 2 and 3 were more frequent in the RMGIC group, whereas the resin group had more scores of 0 and 1, reflecting variations in adhesive remnants. Despite these measurable differences, visual inspection did not reveal any noticeable discoloration. In conclusion, the study demonstrated that RMGIC preserves enamel color more effectively, while resin contributes to greater brightness, with each material showing distinct adhesive retention patterns following orthodontic treatment.

Crespo P et al. (2022)[22] conducted a systematic review to assess the variability in precision, repeatability, and reliability of different spectrophotometers used for tooth colour selection. The increasing demand for accurate and objective shade matching in aesthetic dentistry necessitates reliable digital tools, and this study aimed to clarify whether spectrophotometers differ significantly in performance. A comprehensive literature search was carried out in four major databases MEDLINE (PubMed), Google Scholar, Scopus, and Web of Science along with a manual search of reference lists. The study selection, data extraction, and bias assessments were performed independently by three reviewers using established guidelines: the Newcastle Ottawa tool for in vivo studies, and modified ARRIVE and CONSORT criteria for in vitro studies. Despite variations in experimental designs, none of the included articles followed the ISO_TR_28642_2016 standard for tooth colour measurement, indicating a lack of standardization across studies. Out of 714 initially identified articles, only six met the inclusion criteria. Among these, two studies assessed both precision and repeatability, three focused solely on repeatability, and one evaluated reliability. Due to methodological differences, direct comparisons were limited, and a meta-analysis was not performed. The review concluded that among the devices analyzed, SpectroShade Micro and VITA Easyshade demonstrated relatively better performance in terms of precision and repeatability. However, no spectrophotometer showed a significant advantage in terms of overall reliability. The findings highlight the need for standardized protocols and adherence to ISO guidelines in future research to ensure comparability and consistency in tooth colour assessment.

Yadav JS et al. (2023)[56] conducted a study to monitor the oral hygiene levels of individuals

undergoing treatment with fixed orthodontic appliances. They assessed patients using the Gingival Bleeding Index (GBI), Plaque Index (PI), and Orthodontic Plaque Index (OPI) at three different time points: the first day of treatment (T0), the 15th day (T1), and the 30th day (T2). Ten participants between the ages of 15 and 30 were included in the study. Results demonstrated a noticeable drop in plaque levels from T0 to T2, with a consistent decline in the PI. GBI scores significantly decreased in the first two weeks, but no further change was seen after that. Similarly, OPI scores improved in the first half of the month but plateaued afterward. There were no notable differences in oral hygiene scores between male and female participants. In summary, the findings underline the importance of maintaining good oral hygiene practices during orthodontic treatment, as insufficient care may lead to gingival inflammation. Continuous guidance and regular reinforcement of oral hygiene are essential during the treatment period.

Lopes PC et al. (2023)[7] conducted a systematic review to assess whether new diagnostic tools, such as fluorescence, microradiography, and computed microtomography, could influence the conventional treatment of white spot lesions (WSLs), early signs of caries, increasingly prevalent in orthodontic patients. The review followed PRISMA guidelines, including studies published between 2012 and 2023, with a focus on human studies and both diagnosis and treatment components. After screening 143 references, 20 studies were included. Conventional visual examination was the most common diagnostic method (n=10), followed by fluorescence-based techniques (n=7). Treatment methods primarily included resin infiltration (n=7) and fluoride-based therapies (n=5). Other treatments included self-assembling peptide P11-4, casein phosphopeptide-amorphous calcium phosphate, and home care practices. Some studies also explored combination therapies. The review concluded that while new diagnostic tools offer more detailed lesion

assessment, they do not significantly alter the treatment approach for WSLs. The therapeutic strategies remain largely unchanged, indicating that advancements in diagnostic technologies have not yet translated into major shifts in clinical management of WSLs. This suggests that further research is needed to fully integrate these diagnostic methods into routine clinical practice.

Almutairi A et al. (2023)[57] conducted a systematic literature review titled "Importance of Oral Hygiene in Orthodontic Treatment," aiming to assess the role of oral hygiene in influencing clinical outcomes and maintaining oral health in patients undergoing fixed orthodontic therapy. Following PRISMA guidelines, 28 peer-reviewed studies published between 2018 and 2022, encompassing both clinical trials and observational designs, were included. The findings consistently demonstrated that fixed orthodontic appliances impede natural self-cleansing mechanisms, thereby facilitating increased plaque accumulation, gingival inflammation, and enamel demineralization. Poor oral hygiene was strongly associated with a higher prevalence of white spot lesions, gingivitis, and dental caries. The review highlighted the clinical efficacy of various preventive measures, including fluoride varnishes, chlorhexidine-based gels, antimicrobial mouth rinses, and modified brushing protocols. Additionally, the use of adjunctive oral hygiene devices, such as single-tufted brushes, triple-headed toothbrushes, and water flossers, significantly enhanced plaque control. Furthermore, improved oral hygiene correlated with better psychosocial outcomes, including reduced treatment-related discomfort and enhanced self-perception. The authors concluded that the integration of structured oral hygiene education, individualized hygiene regimens, and regular professional supervision is imperative for the prevention of iatrogenic complications

and the promotion of optimal therapeutic and psychosocial outcomes in orthodontic patients.

Tunca M and Kaya Y. (2023)[58] conducted a study to evaluate the impact of different orthodontic adhesives on enamel color changes in incisors and canines after fixed appliance treatment. The study involved 25 patients, with 300 maxillary and mandibular incisors and canines, who had completed their orthodontic treatment. Four adhesives were tested: Transbond XT, Kurasper F, Grengloo, and Light Bond, each applied to different quadrants of the teeth. Enamel color changes were assessed using the SpectroShade Micro Dental Colour Complete Tooth Analysis System, and color measurements were based on the CIE L, a, b system, with ΔE values calculated to quantify changes. The results indicated significant decreases in lightness (L) and yellowness (b), while color changes in redness (a) were minimal across all groups. Kurasper F showed the least enamel discoloration compared to Grengloo and Light Bond, although the differences were not clinically significant. When incisors and canines were assessed separately, the Kurasper F and Transbond XT groups showed fewer color changes in canines compared to incisors, but overall, the ΔE values (1.83–2.18 for incisors and 1.41–1.95 for canines) were not clinically relevant, suggesting that the choice of adhesive does not lead to meaningful color changes in enamel.

Yaqoob A et al. (2024)[59] conducted a clinical study assessed enamel colour changes following fixed orthodontic treatment using an advanced spectrophotometer. The study involved 60 patients, equally divided into a case group (undergoing fixed orthodontic treatment) and a control group (not receiving fixed orthodontic treatment). Spectrophotometric measurements of tooth colour were taken before

bracket placement and after appliance removal and enamel clean-up, using the CIE L, a, and b values to evaluate lightness, red-green balance, and yellow-blue balance. Significant colour changes were observed, with L decreasing (darker teeth), and a and b increasing (redder and yellower tones). Colour difference values ranged from 1.64 to 2.96, which are perceptible to the human eye. Male and adolescent patients showed greater changes compared to females and adults. The study concluded that fixed orthodontic treatment causes clinically significant enamel colour changes, particularly in younger and male patients, highlighting the importance of aesthetic considerations in treatment planning, especially for patients more susceptible to visible colour alterations. These findings emphasize the need for careful monitoring of tooth color during orthodontic therapy to ensure optimal aesthetic outcomes.

Inchingolo F et al. (2024)[60] conducted a systematic review to assess the structural and color changes in enamel following orthodontic debonding. The study evaluated enamel microfractures, surface roughness, and discoloration caused by fixed orthodontic appliances and various removal techniques. The systematic search identified 14 relevant clinical studies both in vivo and ex vivo following PRISMA guidelines. The review highlighted that ceramic brackets were more prone to causing enamel fractures, especially under high debonding forces exceeding 40 MPa. Pre-existing enamel microcracks (EMCs) were found to increase post-treatment, and patients with prior EMCs exhibited higher tooth sensitivity. Surface roughness, another adverse effect, was significantly influenced by the type of adhesive and polishing method. Polishing with aluminum oxide disks yielded smoother enamel surfaces compared to carbide burs, and newer systems like 30-blade tungsten carbide burs were more effective in preserving enamel integrity. Color alterations were also

documented as a common issue following debonding, with tooth darkening and shifts towards reddish-yellow hues. Although polishing systems and materials like nano-hydroxyapatite were tested, they showed mixed efficacy in preventing discoloration. Notably, adolescents and males were more susceptible to post-treatment enamel color changes. The study concluded that while fixed orthodontic appliances enhance dental aesthetics and function, they often result in undesirable enamel damage. Therefore, careful selection of brackets, adhesives, and finishing protocols is crucial to minimize these effects. Further research is needed to standardize debonding techniques and develop effective strategies for enamel preservation and color maintenance post-orthodontic treatment.

Zhao et al. (2024)[61] conducted a prospective clinical study involving 45 orthodontic patients to assess the effects of fixed orthodontic appliances on oral health and the salivary microbiome using 16S rRNA sequencing. Saliva samples and clinical parameters, including plaque index and brushing frequency, were recorded at baseline (T0) and after six months (T1). Although brushing frequency significantly improved over the treatment period, the plaque index did not decrease, highlighting the persistent difficulty in maintaining effective plaque control in the presence of fixed appliances. This suggests that mechanical cleaning alone may not be sufficient during orthodontic treatment. Microbial analysis revealed increased diversity and richness, with notable shifts in the oral microbiota. There was a significant rise in pathogenic phyla such as Firmicutes and Spirochaetota, and genera including Centipeda, Anaeroglobus, Actinomyces, and Corynebacterium organisms commonly associated with periodontal and cariogenic activity. These changes indicate a dysbiotic microbial shift facilitated by the orthodontic environment. The

study reinforces the importance of rigorous plaque control protocols during treatment. Despite better hygiene behavior, fixed appliances create niches that promote biofilm retention and microbial imbalance, warranting the integration of antimicrobial adjuncts and professional monitoring to prevent oral health complications.

Xia L et al. (2025)[62] presented an expert consensus review focusing on the prevention and treatment of enamel demineralization, specifically white spot lesions (WSLs), during orthodontic treatment. The objective was to provide comprehensive guidance for clinical diagnosis, prevention, and management strategies. The methodology included a consensus-based review of current diagnostic techniques such as visual inspection, digital photography, fluorescence methods, fiber-optic transillumination, and artificial intelligence applications. Findings indicated that the prevalence of WSLs ranged from 23.4% to 75.6%, with higher risks associated with fixed appliances, prolonged treatment duration, poor oral hygiene, and preexisting lesions. The authors emphasized preventive strategies including risk assessment, oral hygiene education, fluoride usage, dietary counseling, and regular monitoring. For treatment, they recommended remineralizing agents like CPP-ACP, resin infiltration for aesthetic restoration, and emerging techniques such as laser therapy and biomimetic remineralization. The conclusion stressed the importance of early prevention, multidisciplinary collaboration, and the potential of AI for personalized WSL risk prediction and monitoring throughout the orthodontic process.

Materials & Method

MATERIALS AND METHOD

STUDY SITE

Department of Orthodontics & Dentofacial Orthopaedics, Santosh Deemed to be University, Ghaziabad.

STUDY DESIGN

Observational study

STUDY SUBJECTS

Patients who reported to the Department of Orthodontics and Dentofacial Orthopaedics, Santosh Dental College and Hospital, for fixed orthodontic treatment with metal braces were included in the study sample.

INCLUSION CRITERIA FOR SELECTION OF STUDY SUBJECTS

- Patients aged between 12 and 30 years undergoing fixed orthodontic treatment with metal brackets.
- Subjects with permanent dentition and no missing anterior teeth.
- Patients with no history of previous orthodontic treatment.
- Patients without any tooth fracture in the upper and lower anterior region.
- Patients with no dental restorations in the upper and lower anterior region.
- Patients with no abnormalities in tooth size and tooth shape in the upper and lower anterior region
- Patients who voluntarily agreed to participate and signed the informed consent form.

EXCLUSION CRITERIA FOR SELECTION OF STUDY SUBJECTS

- Subjects with a history of smoking habit.
- Patients with enamel decalcification.
- Participants presenting with active dental caries.
- Subjects with clinical signs of dental fluorosis.
- Individuals exhibiting white spot lesions on their teeth.
- Participants with intrinsic staining of teeth.
- Subjects diagnosed with enamel or dentinal hypoplasia were excluded.

SAMPLE SIZE

The sample size was calculated using the G power 3.1 software. The power of the study was taken to be 80% and Confidence Interval (C.I.) of 95% was taken and effect size was taken as 0.5292. Based on this, the final sample size will be 31 in this proposed study

t tests - Means: Difference between two dependent means (matched pairs)

Analysis: A priori: Compute required sample size

Input:	Tail(s)	= Two
	Effect size dz	= 0.5292
	α err prob	= 0.05
	Power (1-β err prob)	= 0.80
Output:	Noncentrality parameter δ	= 2.9464609
	Critical t	= 2.0422725
	Df	= 30
	Total sample size	= 31
	Actual power	= 0.8135401

ARMAMENTARIUM

1. For evaluation of tooth colour

- Intraoral spectrophotometer VITA Easyshade® Advance 4.0 (VITA Zahnfabrik, Bad Sackingen, Germany)[13] (Fig.1).
- Infection control shields provided with VITA Easyshade Advance 4.0 kit.
- Cheek retractor (Fig.2).

2. For evaluation of oral hygiene status

Erythrosine dye (Plaque disclosing agent) (Fig.3)

Applicator tip (Fig .4)

Mouth mirror (Fig .5)

Probe (Fig .5)

Kidney tray (Fig .5)

Fig. 01 - VITA Easyshade® Advance 4.0 (VITA Zahnfabrik, Bad Sackingen, Germany)

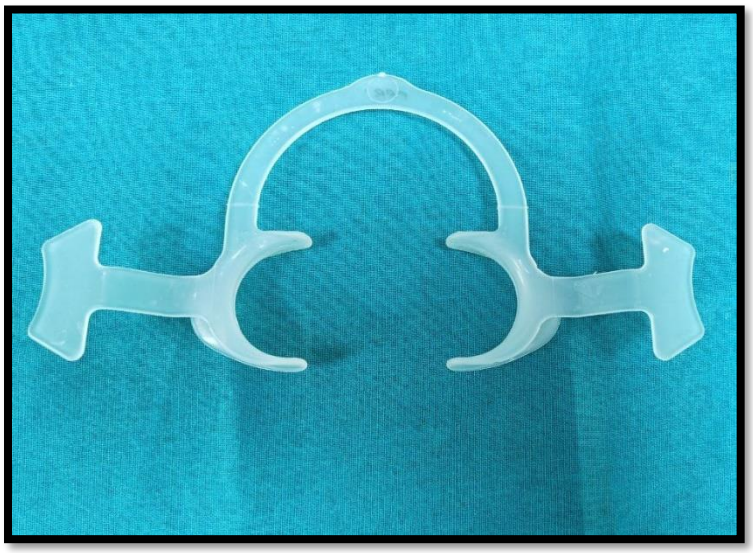


Fig. 2 – Check retractor.

Fig. 3 - Erythrosine dye (plaque disclosing agent)

Fig. 4 – Applicator tip.

Fig. 5 - Mouth mirror, Prob, Kidney tray

METHODOLOGY:

- The study was approved by the Institutional Ethics committee of Santosh Deemed to be University (F. No. SU/2023/2480[15]) (Annexure IV)
- All the participants meeting the criteria for inclusion and exclusion were chosen.
- Participants undergoing fixed orthodontic treatment in in Dept of Orthodontics and Dentofacial Orthopedics, Santosh Dental College, Ghaziabad were selected.

ETHICAL CONSENT

The consent was taken by patients and their parents.

Patient Consent: A written informed consent form was signed by each patient, indicating that they had voluntarily agreed to participate in the study after being fully informed about its purpose, procedures, and their rights as participants.

❖ **Methodology for Baseline Appointment (T0).**

At T0, the baseline clinical procedures were initiated. Oral prophylaxis was first performed using an ultrasonic scaler (Fig.7), followed by polishing with pumice paste (Prime Dental Aster Prophy) and slow-speed contra-angle handpiece (AppleDental, Guangdong JINME Medical Technology Co., Ltd) (Fig.8), followed by bonding of metal MBT slot size of 0.022” × 0.028” prescription according to standard bonding protocols, ensuring removal of excess composite material around each bracket.

After bonding, tooth colour assessment was carried out using the VITA Easyshade Advance 4.0 spectrometer. The device was covered with an infection control sleeve and calibrated according to the manufacturer's instructions (Fig.9). Shade measurements were taken from the labial surfaces of the central incisors, lateral incisors, and canines in both arches, on the cervical (Fig.10), mesial (Fig.11), distal (Fig.12), and incisal

(Fig.13) regions around the brackets. The obtained values of L (lightness), C (chroma), and H (hue) were documented and added to the patient's case history sheet (Fig.14a-d). Following shade evaluation, oral hygiene status was assessed using the Orthodontic Plaque Index. A cheek retractor was placed, and erythrosine disclosing solution was applied to all teeth with a cotton applicator. After 30 seconds, the patient is asked to rinse the mouth with water. The dentition was divided into sextants (S1, S2, S3, S4, S5 and S6) and the buccal surfaces around the brackets were examined for plaque accumulation. Scores were assigned based on the presence of disclosed plaque and recorded in the case history.

- **Methodology for follow up at T1 and T2.**

T1 and T2 follow-up evaluations were conducted at 3 months and 6 months, respectively, after the baseline appointment. Oral hygiene status was first assessed using the Orthodontic Plaque Index. A cheek retractor was inserted, and erythrosin disclosing solution was applied to all teeth using a cotton applicator. After 30 seconds, the patient is asked to rinse the mouth with water, and the dentition was examined by dividing it into sextants (S1, S2, S3, S4, S5 and S6). The buccal surfaces adjacent to the brackets were inspected for plaque accumulation, and scores were assigned and documented accordingly.

Immediately following oral hygiene evaluation, oral prophylaxis was performed to eliminate residual disclosing agent and plaque that could interfere with accurate tooth colour evaluation. This was carried out using an ultrasonic scaler followed by polishing with pumice paste (Prime Dental Aster Prophy) applied via a slow-speed contra-angle handpiece.

Once the teeth were thoroughly cleaned, tooth colour was evaluated using the VITA

Easyshade Advance 4.0 digital spectrometer. The device was calibrated prior to use, and shade measurements were taken from the same anatomical regions on the central incisors, lateral incisors, and canines as recorded during the baseline visit. Values for ΔE, L, C, and H were documented and included in the patient's case records. This protocol was identically followed at both T1 and T2 to facilitate reliable comparison of data over time.

Fig.6 – Evaluation of Oral hygiene using Erythrosine

Fig.7 – Oral prophylaxis using ultrasonic scaler

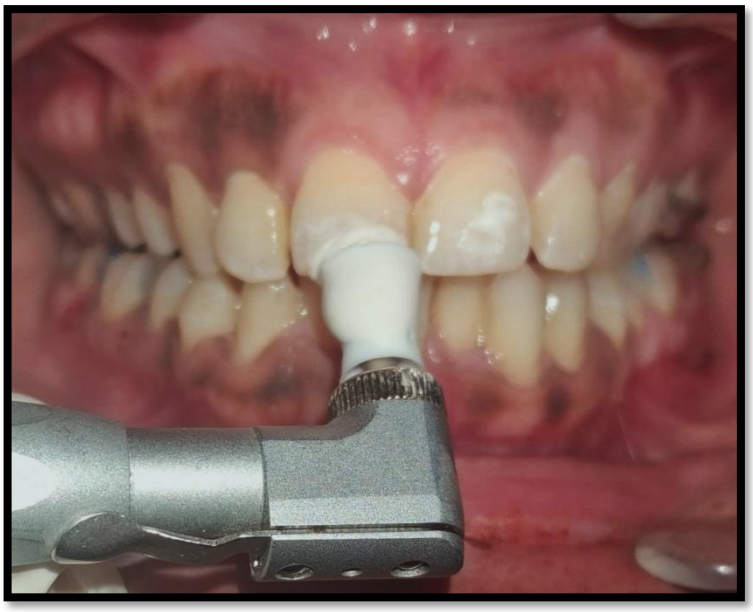


Fig. 8 – Tooth polishing with slow speed contra angle handpiece

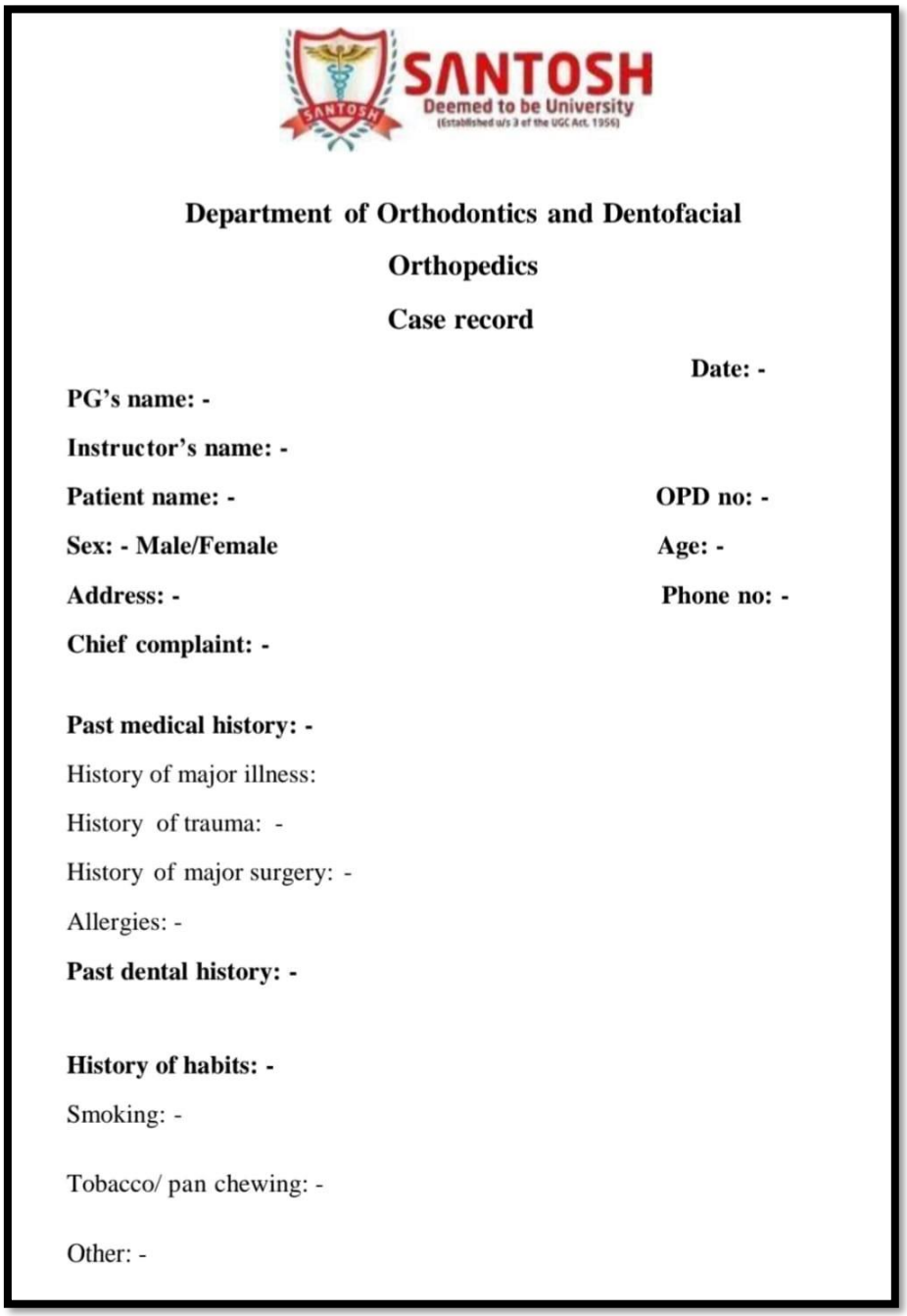
Fig. 9 – Recalibration VITA Easyshade® Advance 4.0

Fig. 10 – Tooth colour evaluation cervical aspect of tooth

Fig.11 – Tooth colour evaluation mesial aspect of tooth

Fig.12 – Tooth colour evaluation distal aspect of tooth

Fig.13 – Tooth colour evaluation incisal aspect of tooth



SANTOSH
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Department of Orthodontics and Dentofacial Orthopedics

Case record

Date: -

PG's name: -

Instructor's name: -

Patient name: - **OPD no: -**

Sex: - Male/Female **Age: -**

Address: - **Phone no: -**

Chief complaint: -

Past medical history: -

History of major illness:

History of trauma: -

History of major surgery: -

Allergies: -

Past dental history: -

History of habits: -

Smoking: -

Tobacco/ pan chewing: -

Other: -

Fig. 14– (a) Patient case record sheet

Intra-oral examination: -

1) No of teeth present
2) Teeth present
3) Decalcification.
4) Dental caries.
5) Fluorosis.
6) White spot lesions.
7) Intrinsic stain of tooth.
8) Enamel and dentinal hypoplasia.
9) Restorations.
10) Prosthetic crowns.
11) Oral hygiene status of the patient

(i) Orthodontic plaque index

Sextant	score		
	T0	T1	T2
S1			
S2			
S3			
S4			
S5			
S6			

(ii) Orthodontic plaque index score of dentitions (highest scoreamong all sextants): -

Score		
T0	T1	T2

Fig. 14– (b) Patient case record sheet

(iii)Orthodontic plaque index status of dentitions

Score		
T0	T1	T2

12. Tooth color evaluation

i) Evaluation of tooth color in the right maxillary arch

Time	Central incisor				Lateral incisor				Canine			
	Cervical	Mesial	Distal	Incisal	Cervical	Mesial	Distal	Incisal	Cervical	Mesial	Distal	Incisal
T0												
ΔE												
L												
C												
h												
T1												
ΔE												
L												
C												
h												
T2												
ΔE												
L												
C												
h												

Fig. 14– (c) Patient case record sheet

ii) Evaluation of tooth color in the left maxillary arch teeth

Time	Central incisor				Lateral incisor				Canine			
	Cervical	Mesial	Distal	Incisal	Cervical	Mesial	Distal	Incisal	Cervical	Mesial	Distal	Incisal
T0												
ΔE												
L												
C												
h												
T1												
ΔE												
L												
C												
h												
T2												
ΔE												
L												
C												
h												

Fig. 14– (d) Patient case record sheet

STATISTICAL ANALYSIS

Statistical analysis was be done with Statistical Package for Social Sciences (IBM SPSS Statistic for window, version 26.0. Armonk, NY: IBM Corp.) at 95% CI and 80% power to the study.

Kolmogorov-Smirnov and Shapiro Wilk test will be done to check for normal distribution of the data.

Descriptive statistics was be performed in terms of, mean and standard deviation, frequency and percentage.

Repeated Measures Tukey's Post hoc test was applied to compare the OHIS, H, L, C and Delta E between different time intervals.

Pearson's correlation test was applied to correlate OHIS and Delta E values

Statistical significance will be calculated at $p<0.05$ and $p<0.001$ will be considered highly statistically significant.

Results

RESULTS

Table No.1 Age Distribution mean and std deviation.

	N	Minimum	Maximum	Mean	Std. Deviation
Age	32	14.00	30.00	19.3438	3.81516

- **Age Distribution mean and std deviation.**

Table no.1 shows the participants ranged in age from 14 to 30 years, with a mean age of 19.34 ± 3.82 years.

Table No.2 Gender Distribution mean and std deviation.

Gender	Frequency	Percent
Female	25	78.12
Male	7	21.87
Total	32	100.

- **Gender Distribution mean and std deviation.**

Table no2 shows among the 32 participants, 25 were females (78.12%) and 7 were males (21.87%), indicating a predominantly female study population.

Table No.3 Evaluation of Lightness (L) in Maxillary Anterior Teeth at T0, T1, and T2 for Cervical, Mesial, Distal and Incisal Surfaces.

Teeth	Surface	Time	N	Mean	Std.Deviation	Minimum	Maximum
Maxillary Right Central Incisor	Cervical	T0	32	1.243	4.78	-9.1	9
		T1	32	4.524	8.137	-11	19.4
		T2	32	6.427	10.064	-14.7	22.5
	Mesial	T0	32	-0.985	7.165	-28	9.9
		T1	32	4.667	9.142	-11.8	19.3
		T2	32	5.395	10.917	-16.9	22.4
	Distal	T0	32	-0.339	5.936	-14.4	8.3
		T1	32	3.875	9.119	-15.5	18.6
		T2	32	5.61	10.113	-12.8	21.7
	Incisal	T0	32	-0.998	7.711	-18.1	9.7
		T1	32	5.389	9.413	-17.5	18.8

		T2	32	6.814	10.324	-15.5	21.24
Maxillary Right Lateral Incisor	Cervical	T0	32	0.32	5.609	-13.4	9.6
		T1	32	6.003	7.769	-12.7	17.6
		T2	32	7.521	8.901	-16.4	20.7
	Mesial	T0	32	-1.571	7.503	-15.8	11.7
		T1	32	4.265	10.577	-17.5	20
		T2	32	6.259	12.528	-20.6	23.1
	Distal	T0	32	-2.149	8.057	-23	8.2
		T1	32	2.678	11.501	-24	19.9
		T2	32	5.653	12.077	-18	23
	Incisal	T0	32	-1.913	7.836	-15.4	12.7
		T1	32	3.049	11.091	-18.6	19.6
		T2	32	4.34	12.606	-15.8	22.7
Maxillary Right Canine	Cervical	T0	32	1.57	7.935	-16.5	16
		T1	32	5.054	10.172	-19.8	19.7
		T2	32	6.44	10.72	-14.8	22.8
	Mesial	T0	32	-0.635	7.245	-15.6	11.4
		T1	32	4.974	9.091	-18.2	17.6
		T2	32	7.302	9.863	-15.8	17.3
	Distal	T0	32	-0.453	7.511	-14.2	12.8
		T1	32	5.006	9.796	-15.6	18.4
		T2	32	6.85	10.897	-15.1	21.5
	Incisal	T0	32	0.128	5.56	-8.9	10.1
		T1	32	4.343	9.43	-13.9	17.7
		T2	32	16.265	55.082	-16.1	313
Maxillary Left Central Incisor	Cervical	T0	32	1.615	5.437	-15.5	9.1
		T1	32	5.324	8.748	-17.8	20.9
		T2	32	5.790	11.967	-13.8	33.5
	Mesial	T0	32	1.521	5.142	-8.9	10.2
		T1	32	5.384	8.894	-17.6	18.9
		T2	32	6.359	10.407	-15.7	22
	Distal	T0	32	0.646	6.667	-10.3	22
		T1	32	3.307	8.515	-11.5	13.3
		T2	32	3.764	10.765	-15.2	16.4
	Incisal	T0	32	-1.681	8.106	-28.4	19.4
		T1	32	2.558	10.855	-30.4	17.8
		T2	32	4.692	12.941	-33.2	20.9
Maxillary Left Lateral Incisor	Cervical	T0	32	0.918	5.606	-13.2	7.6
		T1	32	6.178	7.894	-14.3	19.9
		T2	32	7.915	9.189	-17.4	23
	Mesial	T0	32	-0.262	6.680	-15.2	8.9
		T1	32	5.125	9.876	-19.4	18.8
		T2	32	6.403	10.765	-22.5	21.9
	Distal	T0	32	0.02	6.147	-14.6	8.8

		T1	32	4.303	9.763	-18.8	17.7
		T2	32	4.118	12.296	-21.9	20.8
	Incisal	T0	32	1.14	5.069	-9.5	12.1
		T1	32	3.787	8.536	-12.8	15.7
		T2	32	5.406	9.499	-16.2	18.6
Maxillary Left Canine	Cervical	T0	32	1.917	6.446	-10.7	10.8
		T1	32	4.892	9.189	-14.2	15.4
		T2	32	6.420	10.197	-16.5	18.5
	Mesial	T0	32	0.784	5.441	-13.5	11.2
		T1	32	6.334	9.313	-13.9	17.7
		T2	32	5.748	10.408	-16.5	20.8
	Distal	T0	32	1.403	9.387	-14.7	38
		T1	32	5.037	8.989	-18.9	17.4
		T2	32	6.962	9.526	-22	16.6
	Incisal	T0	32	2.837	13.167	-8.7	71.1
		T1	32	4.303	8.329	-18.7	20.4
		T2	32	5.797	10.131	-15.9	23.5

- **Evaluation of Lightness (L) in Maxillary Anterior Teeth at T0, T1, and T2 for Cervical, Mesial, Distal and Incisal Surfaces table 3 shows.**

Maxillary Right Central Incisor

The cervical surface showed a gradual increase in lightness from 1.24 ± 4.78 at T0 to 4.52 ± 8.13 at T1, and further to 6.43 ± 10.06 at T2, indicating progressive whitening. On the mesial surface, the mean lightness increased from -0.99 ± 7.17 at T0 to 4.67 ± 9.14 at T1, and 5.40 ± 10.92 at T2, reflecting a significant improvement over time. Distal surface measurements progressed from -0.34 ± 5.94 at T0 to 3.88 ± 9.12 at T1, and 5.61 ± 10.11 at T2, showing increased brightness. The incisal surface also showed lightness improvement from -1.00 ± 7.71 at T0 to 5.39 ± 9.41 at T1, and 6.81 ± 10.32 at T2.

Maxillary Right Lateral Incisor

The cervical surface had a mean lightness of 0.33 ± 5.61 at T0, which increased to 6.00 ± 7.77 at T1, and further to 7.52 ± 8.90 at T2. On the mesial surface, values increased from -1.57 ± 7.50 at T0 to 4.27 ± 10.58 at T1, and 6.26 ± 12.53 at T2. The distal surface progressed from -2.15 ± 8.06 at T0 to 2.68 ± 11.50 at T1, and 5.65 ± 12.08 at T2, indicating marked improvement. Lightness on the incisal surface also increased from -1.91 ± 7.84 at T0 to 3.05 ± 11.09 at T1, and 4.34 ± 12.61 at T2.

Maxillary Right Canine

Cervical surface showed an increase from 1.57 ± 7.94 at T0 to 5.05 ± 10.17 at T1, and 6.45 ± 10.72 at T2. On the mesial surface, mean lightness values improved from -0.64 ± 7.25 at T0 to 4.97 ± 9.09 at T1, and 7.30 ± 9.86 at T2. The distal surface increased from -0.45 ± 7.51 at T0 to 5.01 ± 9.80 at T1, and 6.85 ± 10.90 at T2. Notably, the incisal surface jumped from 0.13 ± 5.56 at T0 to 4.34 ± 9.43 at T1, and significantly to 16.27 ± 55.08 at T2, showing wide variability due to an outlier.

Maxillary Left Central Incisor

Cervical lightness improved from 1.62 ± 5.44 at T0 to 5.32 ± 8.75 at T1, and 5.79 ± 11.97 at T2. Mesial surface values increased from 1.52 ± 5.14 at T0 to 5.38 ± 8.89 at T1, and 6.36 ± 10.41 at T2. On the distal surface, the mean changed from 0.65 ± 6.67 at T0 to 3.31 ± 8.52 at T1, and 3.76 ± 10.77 at T2. The incisal surface showed improvement from -1.68 ± 8.11 at T0 to 2.56 ± 10.86 at T1, and 4.69 ± 12.94 at T2.

Maxillary Left Lateral Incisor

Cervical surface lightness increased from 0.92 ± 5.61 at T0 to 6.18 ± 7.89 at T1, and 7.92 ± 9.19 at T2. The mesial surface improved from -0.26 ± 6.68 at T0 to 5.13 ± 9.88

at T1, and 6.40 ± 10.77 at T2. Distal surface values changed from 0.02 ± 6.15 at T0 to 4.30 ± 9.76 at T1, and slightly to 4.12 ± 12.30 at T2. On the incisal surface, values rose from 1.14 ± 5.07 at T0 to 3.79 ± 8.54 at T1, and 5.41 ± 9.50 at T2.

Maxillary Left Canine

The cervical surface showed increased lightness from 1.92 ± 6.45 at T0 to 4.89 ± 9.19 at T1, and 6.42 ± 10.20 at T2. Mesial surface measurements progressed from 0.78 ± 5.44 at T0 to 6.33 ± 9.31 at T1, and slightly decreased to 5.75 ± 10.41 at T2. The distal surface increased from 1.40 ± 9.39 at T0 to 5.04 ± 8.99 at T1, and 6.96 ± 9.53 at T2. Incisal lightness improved from 2.84 ± 13.17 at T0 to 4.30 ± 8.33 at T1, and 5.80 ± 10.13 at T2.

Table No.4 Evaluation of Chroma (C) in Maxillary Anterior Teeth at T0, T1, and T2 for cervical, mesial, distal and incisal surfaces: -

Teeth	Surface	Time	N	Mean	Std.Deviation	Minimum	Maximum
Maxillary Right Central Incisor	Cervical	T0	32	1.143	3.229	-6	6.7
		T1	32	3.432	7.432	-9.5	10.9
		T2	32	4.495	9.727	-13.2	13.9
	Mesial	T0	32	-0.139	3.793	-7.1	5.4
		T1	32	2.967	7.681	-12.4	10.3
		T2	32	0.964	13.807	-35.2	15.6
	Distal	T0	32	0.24	4.148	-7.2	8.2
		T1	32	3.3	7.827	-11.5	12.5
		T2	32	1.375	11.697	-14.7	14.9
	Incisal	T0	32	-1.176	4.385	-9.8	9.24
		T1	32	2.72	8.391	-11.3	17.11
		T2	32	1.404	12.638	-14.8	15.94
Maxillary Right Lateral Incisor	Cervical	T0	32	0.409	4.959	-12.3	13.9
		T1	32	3.59	8.113	-18.6	11.5
		T2	32	3.515	11.204	-15.7	14.6
	Mesial	T0	32	-0.393	4.083	-7.7	7.4
		T1	32	3.39	7.714	-12.7	11.2
		T2	32	4.509	12.185	-14.4	14.9
	Distal	T0	32	-1.157	4.401	-10.2	6.5

		T1	32	3.023	8.317	-14.6	12.2
		T2	32	4.867	11.48	-14.2	15.9
	Incisal	T0	32	-2.251	6.135	-16.7	9.2
		T1	32	4.392	9.619	-13.9	20.9
		T2	32	4.720	12.696	-16.1	24
Maxillary Right Canine	Cervical	T0	32	0.62	4.636	-8	6.2
		T1	32	4.3	7.608	-11.5	11.5
		T2	32	7.216	10.44	-13.4	16.9
	Mesial	T0	32	-0.254	5.242	-12	9.25
		T1	32	4.295	8.023	-12.8	15
		T2	32	7.573	10.903	-16.5	18.1
	Distal	T0	32	-0.917	5.771	-11.3	7.6
		T1	32	3.871	8.906	-15.6	13
		T2	32	4.675	12.042	-16.1	16.7
	Incisal	T0	32	-0.884	5.755	-15.4	7.4
		T1	32	4.963	7.59	-11.4	18.9
		T2	32	4.85	11.89	-17.4	16.3
Maxillary Left Central Incisor	Cervical	T0	32	0.629	4.316	-9.2	6.7
		T1	32	3.036	7.906	-12	11.2
		T2	32	4.867	11.39	-15.7	15.3
	Mesial	T0	32	0.683	4.995	-10.9	15.4
		T1	32	2.411	8.349	-13.9	11.5
		T2	32	2.977	10.938	-17	15
	Distal	T0	31	0.697	10.194	-18.3	43
		T1	32	1.31	9.699	-22.5	11.7
		T2	32	4.254	17.099	-25.3	72
	Incisal	T0	32	-3.404	6.236	-19.6	9.26
		T1	32	1.182	10.266	-22.1	19.9
		T2	32	1.717	13.912	-32.4	23
Maxillary Left Lateral Incisor	Cervical	T0	32	0.043	5.216	-14.6	10.6
		T1	32	2.828	8.557	-11.6	18.8
		T2	32	3.128	11.973	-15.3	21.9
	Mesial	T0	32	-0.99	6.46	-15.9	13.4
		T1	32	1.381	10.098	-20.1	15.2
		T2	32	2.24	12.248	-23.2	18.3
	Distal	T0	31	-1.116	7.524	-15.2	18
		T1	32	1.454	10.45	-21.3	14.60
		T2	32	3.967	12.95	-22.5	17.7
	Incisal	T0	32	-1.603	6.497	-16	13.9
		T1	32	2.608	11.126	-20.2	30
		T2	32	3.846	12.139	-23.3	21.2
Maxillary Left Canine	Cervical	T0	32	0.514	4.618	-13.5	6.1
		T1	32	3.714	7.955	-17.7	13.11
		T2	32	4.429	11.094	-20.8	13.9

	Mesial	T0	31	1.528	15.244	-12.3	79
		T1	32	2.621	8.442	-13.1	13.7
		T2	32	3.789	11.685	-16.2	16.8
	Distal	T0	32	-0.825	4.901	-10.8	7.4
		T1	32	2.209	9.102	-14.9	13.2
		T2	32	4.796	10.7	-13.8	16.3
	Incisal	T0	32	0.471	4.127	-9	7.4
		T1	32	4.034	7.485	-13.9	11.5
		T2	32	5.765	9.741	-16.2	15.2

- **Evaluation of Chroma (C) in Maxillary Anterior Teeth at T0, T1, and T2 for cervical, mesial, distal and incisal surfaces table no.4: -**

Maxillary Right Central Incisor:

Cervical Surface: The chroma increased progressively from T0 (1.14 ± 3.23) to T1 (3.43 ± 7.43) and further to T2 (4.50 ± 9.73), indicating a gradual intensification of colour saturation. Mesial Surface: A negative mean at T0 (-0.14 ± 3.79) shifted to a peak at T1 (2.97 ± 7.68), followed by a reduction at T2 (0.96 ± 13.81), suggesting initial increase in chroma which slightly regressed. Distal Surface: An upward trend in chroma from T0 (0.24 ± 4.15) to T1 (3.30 ± 7.83) was noted, with a decrease at T2 (1.38 ± 11.70). Incisal Surface: The chroma changed from negative at T0 (-1.18 ± 4.39) to positive at T1 (2.72 ± 8.39), then slightly decreased at T2 (1.40 ± 12.64), indicating a marked color saturation shift initially.

Maxillary Right Lateral Incisor:

Cervical Surface: There was a notable increase in chroma from T0 (0.41 ± 4.96) to T1 (3.59 ± 8.11), remaining stable at T2 (3.52 ± 11.20).

Mesial Surface: Chroma transitioned from negative at T0 (-0.39 ± 4.08) to positive at T1 (3.39 ± 7.71) and continued to rise at T2 (4.51 ± 12.19).

Distal Surface: An initial negative chroma (-1.16 ± 4.40 at T0) increased steadily to T1 (3.02 ± 8.32) and further to T2 (4.87 ± 11.48).

Incisal Surface: The chroma increased substantially from T0 (-2.25 ± 6.14) to T1 (4.39 ± 9.62) and continued to T2 (4.72 ± 12.70), indicating strong enhancement of colour intensity.

Maxillary Right Canine:

Cervical Surface: A progressive increase in chroma was observed from T0 (0.62 ± 4.64) to T1 (4.30 ± 7.61) and T2 (7.22 ± 10.45). Mesial Surface: The chroma increased notably across time points: T0 (-0.25 ± 5.24), T1 (4.30 ± 8.02), and T2 (7.57 ± 10.90). Distal Surface: Starting from a negative value (-0.92 ± 5.77 at T0), chroma rose through T1 (3.87 ± 8.91) to T2 (4.68 ± 12.04). Incisal Surface: The values progressed from T0 (-0.88 ± 5.76) to T1 (4.96 ± 7.59), with minimal change at T2 (4.85 ± 11.89).

Maxillary Left Central Incisor:

Cervical Surface: The mean chroma improved from T0 (0.63 ± 4.32) to T1 (3.04 ± 7.91) and further to T2 (4.87 ± 11.39). Mesial Surface: An increase was observed from T0 (0.68 ± 5.00) to T1 (2.41 ± 8.35), and continued at T2 (2.98 ± 10.94). Distal Surface: A large variability was noted, with chroma rising from T0 (0.70 ± 10.19) to T1 (1.31 ± 9.70), and peaking at T2 (4.25 ± 17.10). Incisal Surface: From a negative baseline (T0: -3.40 ± 6.24), chroma shifted to positive at T1 (1.18 ± 10.27) and T2 (1.72 ± 13.91).

Maxillary Left Lateral Incisor:

Cervical Surface: The chroma increased from T0 (0.04 ± 5.22) to T1 (2.83 ± 8.56) and T2 (3.13 ± 11.97). Mesial Surface: A rise from T0 (-0.99 ± 6.46) to T1 (1.38 ± 10.10) and to T2 (2.24 ± 12.25) was noted.

Distal Surface: Anomalous high mean values were recorded at T1 (1430.02 ± 8081.73) and T2 (1432.57 ± 8081.51), which are likely data entry or measurement errors and should be verified. Incisal Surface: A progressive rise was seen from T0 (-1.60 ± 6.50) to T1 (2.61 ± 11.13) and to T2 (3.85 ± 12.14).

Maxillary Left Canine:

Cervical Surface: The chroma increased from T0 (0.51 ± 4.62) to T1 (3.71 ± 7.96) and further to T2 (4.43 ± 11.09). Mesial Surface: An elevated baseline at T0 (1.53 ± 15.24) was followed by increased values at T1 (2.62 ± 8.44) and T2 (3.79 ± 11.69). Distal Surface: Starting from T0 (-0.83 ± 4.90), chroma rose to T1 (2.21 ± 9.10) and peaked at T2 (4.80 ± 10.70). Incisal Surface: A clear progression was seen from T0 (0.47 ± 4.13) to T1 (4.03 ± 7.49) and further to T2 (5.77 ± 9.74).

Table no.5 Evaluation of Hue (h) in Maxillary Anterior Teeth: -

Teeth	Surface	Time	n	Mean	Std. Deviation	Minimum	Maximum
Maxillary Right Central Incisor	Cervical	T0	32	-5.193	4.22	-13.9	3.33
		T1	32	-2.512	11.391	-24	18.1
		T2	32	-1.13	13.08	-22.7	21.2
	Mesial	T0	32	-2.558	4.75	-13.5	6
		T1	32	-0.577	11.354	-32.5	19.7
		T2	32	-0.161	14.129	-31.2	22.8
	Distal	T0	32	-0.803	6.319	-11	22
		T1	32	-0.172	10.296	-27	18.5
		T2	32	1.252	12.465	-22.2	17.5
	Incisal	T0	32	1.653	7.389	-15.8	28
		T1	32	0.347	10.709	-30.1	20.6
		T2	32	1.394	13.354	-29.2	23.7
Maxillary Right Lateral	Cervical	T0	32	-2.378	9.327	-28.9	29.9
		T1	32	1.9	11.491	-22	31.9

Incisor		T2	32	1.181	14.749	-19.2	34.7
	Mesial	T0	32	-1.168	4.1493	-12.5	7.4
		T1	32	-0.075	10.464	-36.9	10.9
		T2	32	1.781	11.784	-15.5	14.9
	Distal	T0	32	-1.095	6.517	-14.1	18.4
		T1	32	1.601	14.322	-52.4	22.6
		T2	32	3.179	13.576	-21.2	25.4
	Incisal	T0	32	-0.323	7.923	-21.4	13.9
		T1	32	0.582	12.428	-35.6	23.9
		T2	32	2.06	15.147	-31.9	26.7
Maxillary Right Canine	Cervical	T0	32	-5.728	6.982	-30.3	4.2
		T1	32	-0.687	12.86	-32.2	32
		T2	32	-2.05	16.222	-30.1	34.8
	Mesial	T0	32	-2.336	6.061	-23.6	13.3
		T1	32	1.444	11.414	-32	26.1
		T2	32	-1.417	15.13	-30.1	28.9
	Distal	T0	32	-3.8	5.962	-22.7	7.4
		T1	32	0.341	11.339	-29	25.2
		T2	31	-0.467	15.196	-29.2	28
	Incisal	T0	32	-1.206	5.472	-23.4	7.4
		T1	32	1.175	9.461	-20.2	10.9
		T2	32	4.396	12.432	-17.4	14.6
Maxillary left Central Incisor	Cervical	T0	32	-3.714	4.784	-14.6	4.8
		T1	32	-3.654	10.961	-24.2	13.4
		T2	32	-2.673	13.252	-23.6	16.5
	Mesial	T0	32	0.839	7.891	-13.1	29
		T1	32	0.464	10.28	-22.7	13.4
		T2	32	0.407	13.39	-22.8	16.5
	Distal	T0	32	0.915	9.137	-7.5	42.7
		T1	32	0.344	12.369	-25.9	44.2
		T2	32	1.278	15.364	-24.5	45.5
	Incisal	T0	32	-0.408	11.642	-34.9	21.3
		T1	32	1.754	12.256	-34.1	19.9
		T2	32	5.888	12.828	-17.8	23
Maxillary Left Lateral Incisor	Cervical	T0	32	-2.796	10.132	-21.5	34.6
		T1	32	-0.887	13.295	-27.5	22.9
		T2	32	-2.393	14.357	-28.8	19
	Mesial	T0	32	-0.724	6.472	-23.1	10.6
		T1	32	0.259	11.438	-27.6	20
		T2	32	3.843	12.899	-26.9	16.7
	Distal	T0	32	-1.832	10.345	-34	34
		T1	32	-0.101	14.545	-33.8	35.7
		T2	32	0.88	15.475	-31.1	37
	Incisal	T0	32	1.28	6.535	-8	18.3
		T1	32	2.467	9.541	-13.3	18.1
		T2	32	3.605	13.539	-16.1	25.1
Maxillary Left Canine	Cervical	T0	32	-4.377	7.082	-25.2	10.2
		T1	32	-3.671	11.31	-27.2	15
		T2	32	-4.127	14.24	-30	18.1
	Mesial	T0	32	-2.495	5.634	-24.3	9.35

		T1	32	-1.867	10.167	-26.3	13.9
		T2	32	-1.807	14.229	-24.7	17
	Distal	T0	32	-4.140	9.161	-39.9	7.4
		T1	32	-3.641	12.584	-34.2	10.9
		T2	32	-4.159	15.329	-34.2	14.6
	Incisal	T0	32	-5.093	10.085	-33.9	7.4
		T1	32	-1.8	14.06	-30.7	35.6
		T2	32	-0.19	16.71	-33.5	36.9

- **Evaluation of Hue (h) in Maxillary Anterior Teeth table no 5 shows: -**

Maxillary Right Central Incisor (CI) table no.5 shows.

At the cervical surface, the hue at baseline (T0) was −5.19 ± 4.22, which improved to −2.51 ± 11.39 at T1 and further to −1.13 ± 13.08 at T2. The mesial surface showed a hue of −2.56 ± 4.75 at T0, changing to −0.58 ± 11.35 at T1 and −0.16 ± 14.13 at T2. For the distal surface, the values progressed from −0.80 ± 6.32 at T0 to −0.17 ± 10.30 at T1 and then to 1.25 ± 12.47 at T2. The incisal surface had an initial hue of 1.65 ± 7.39, which slightly declined to 0.35 ± 10.71 at T1 and increased again to 1.39 ± 13.35 at T2.

Maxillary Right Lateral Incisor (LI)

The cervical surface hue was −2.38 ± 9.33 at T0, rising to 1.90 ± 11.49 at T1 and slightly reducing to 1.18 ± 14.75 at T2. On the mesial surface, values changed from −1.17 ± 4.15 at T0 to −0.08 ± 10.46 at T1 and then increased to 1.78 ± 11.78 at T2. The distal surface values shifted from −1.10 ± 6.52 at T0 to 1.60 ± 14.32 at T1 and 3.18 ± 13.58 at T2. On the incisal surface, the hue progressed from −0.32 ± 7.92 at T0 to 0.58 ± 12.43 at T1 and 2.06 ± 15.15 at T2.

Maxillary Right Canine

Cervical hue values improved from −5.73 ± 6.98 at T0 to −0.69 ± 12.86 at T1 and −2.05 ± 16.22 at T2. Mesial values shifted from −2.34 ± 6.06 at T0 to 1.44 ± 11.41 at

T1, then decreased to −1.42 ± 15.13 at T2. At the distal surface, values improved from −3.80 ± 5.96 at T0 to 0.34 ± 11.34 at T1 and slightly reduced to −0.47 ± 15.20 at T2. The incisal surface showed a shift from −1.21 ± 5.47 at T0 to 1.18 ± 9.46 at T1 and further to 4.40 ± 12.43 at T2.

Maxillary Left Central Incisor

The cervical surface hue was −3.71 ± 4.78 at T0, slightly improved to −3.65 ± 10.96 at T1, and further to −2.67 ± 13.25 at T2. The mesial surface showed 0.84 ± 7.89 at T0, 0.46 ± 10.28 at T1, and 0.41 ± 13.39 at T2. On the distal surface, hue values were 0.92 ± 9.14 at T0, 0.34 ± 12.37 at T1, and 1.28 ± 15.36 at T2. Incisal surface values shifted from −0.41 ± 11.64 at T0 to 1.75 ± 12.26 at T1 and 5.89 ± 12.83 at T2.

Maxillary Left Lateral Incisor

Cervical values were −2.80 ± 10.13 at T0, improving to −0.89 ± 13.30 at T1, and slightly declining to −2.39 ± 14.36 at T2. On the mesial surface, hue increased from −0.72 ± 6.47 at T0 to 0.26 ± 11.44 at T1 and then rose further to 3.84 ± 12.90 at T2. Distal values were −1.83 ± 10.35 at T0, −0.10 ± 14.55 at T1, and 0.88 ± 15.48 at T2. The incisal surface showed progressive improvement from 1.28 ± 6.54 at T0 to 2.47 ± 9.54 at T1 and 3.61 ± 13.54 at T2.

Maxillary Left Canine

Cervical surface hue values were −4.38 ± 7.08 at T0, −3.67 ± 11.31 at T1, and −4.13 ± 14.24 at T2. On the mesial surface, values improved slightly from −2.50 ± 5.63 at T0 to −1.87 ± 10.17 at T1 and remained similar at −1.81 ± 14.23 at T2. Distal surface hue was −4.14 ± 9.16 at T0, −3.64 ± 12.58 at T1, and −4.16 ± 15.33 at T2. The incisal surface showed considerable improvement from −5.09 ± 10.09 at T0 to −1.80 ± 14.07 at T1 and −0.19 ± 16.71 at T2.

Table no.6 Pairwise Comparison by Tukey's Test for Lightness Between T0, T1 and T2.

Teeth		Time	Time	Mean Difference	Std. Error	P Value	95% Confidence Interval	
							Lower Bound	Upper Bound
Maxillary Right Central incisor	Cervical	T0	T1	-3.280	1.991	.231	-8.024	1.462
		T0	T2	-5.184	1.991	.029	-9.927	-.440
		T1	T2	-1.903	1.991	.607	-6.646	-2.840
	Mesial	T0	T1	-5.653	2.300	.042	-11.133	-.172
		T0	T2	-6.380	2.300	.018	-11.861	-.900
		T1	T2	-.727	2.300	.946	-6.208	4.752
	Distal	T0	T1	-4.215	2.144	.126	-9.322	.891
		T0	T2	-5.950	2.144	.018	-11.057	-.843
		T1	T2	-1.734	2.144	.698	-6.841	3.372
	Incisal	T0	T1	-6.387	2.303	.018	-11.873	-.901
		T0	T2	-7.812	2.303	.003	-13.298	-2.326
		T1	T2	-1.425	2.303	.810	-6.911	4.060
Maxillary Right lateral incisor	Cervical	T0	T1	-5.678	1.887	.009	-10.174	-1.181
		T0	T2	-7.196	1.887	.001	-11.693	-2.700
		T1	T2	-1.518	1.887	.701	-6.015	2.977
	Mesial	T0	T1	-5.837	2.602	.069	-12.036	.361
		T0	T2	-7.831	2.602	.009	-14.030	-1.632
		T1	T2	-1.993	2.602	.725	-8.192	4.205
	Distal	T0	T1	-4.828	2.673	.173	-11.195	1.539
		T0	T2	-7.802	2.673	.012	-14.170	-1.435
		T1	T2	-2.974	2.673	.509	-9.342	3.393
	Incisal	T0	T1	-4.962	2.674	.158	-11.332	1.407
		T0	T2	-6.253	2.674	.056	-12.623	.117
		T1	T2	-1.290	2.674	.880	-7.660	5.079
Maxillary Right Canine	Cervical	T0	T1	-3.484	2.421	.325	-9.251	2.282
		T0	T2	-4.877	2.421	.114	-10.644	.889
		T1	T2	-1.393	2.421	.834	-7.159	4.373
	Mesial	T0	T1	-5.609	2.200	.033	-10.850	-.3681
		T0	T2	-7.937	2.200	.001	-13.178	-2.696
		T1	T2	-2.328	2.200	.542	-7.569	2.913
	Distal	T0	T1	-5.459	2.376	.061	-11.120	.201
		T0	T2	-7.303	2.376	.008	-12.964	-1.642
		T1	T2	-1.843	2.376	.719	-7.504	3.817
	Incisal	T0	T1	-4.215	8.105	.862	-23.522	15.091
		T0	T2	-16.137	8.105	.120	-35.444	3.169
		T1	T2	-11.921	8.105	.310	-31.228	7.385
Maxillary Left central incisor	Cervical	T0	T1	-3.709	2.279	.239	-9.137	1.719
		T0	T2	-4.175	2.279	.165	-9.603	1.253

		T1	T2	-.465	2.279	.977	-5.894	4.962
	Mesial	T0	T1	-3.862	2.110	.166	-8.890	1.165
			T2	-4.837	2.110	.062	-9.865	.190
		T1	T2	-.975	2.110	.889	-6.002	4.052
	Distal	T0	T1	-2.661	2.225	.459	-7.962	2.640
		T0	T2	-3.117	2.225	.345	-8.418	2.184
		T1	T2	-.456	2.207	.977	-5.715	4.803
	Incisal	T0	T1	-4.240	2.704	.265	-10.681	2.200
		T0	T2	-6.374	2.704	.053	-12.815	.067
		T1	T2	-2.133	2.704	.711	-8.574	4.307
Maxillary Left Lateral incisor	Cervical	T0	T1	-5.259	1.926	.021	-9.848	-.670
		T0	T2	-6.996	1.926	.001	-11.586	-2.407
		T1	T2	-1.737	1.926	.641	-6.326	2.851
	Mesial	T0	T1	-5.387	2.31	.057	-10.910	.134
		T0	T2	-6.665	2.318	.014	-12.188	-1.143
		T1	T2	-1.278	2.318	.846	-6.800	4.244
	Distal	T0	T1	-4.282	2.433	.189	-10.079	1.514
		T0	T2	-4.097	2.433	.217	-9.894	1.698
		T1	T0	.184	2.433	.997	-5.611	5.981
	Incisal	T0	T1	-2.646	1.983	.380	-7.370	2.077
		T0	T2	-4.265	1.983	.085	-8.989	.458
		T1	T2	-1.618	1.983	.694	-6.342	3.105
Max. Left Canine	Cervical	T0	T1	-2.975	2.188	.366	-8.189	2.238
		T0	T2	-4.503	2.188	.105	-9.716	.710
		T1	T2	-1.527	2.188	.765	-6.741	3.685
	Mesial	T0	T1	-5.550	2.158	.031	-10.691	-.408
		T0	T2	-4.964	2.175	.063	-10.146	.218
		T1	T2	.586	2.175	.961	-4.596	5.768
	Distal	T0	T1	-3.634	2.326	.267	-9.174	1.905
		T0	T2	-5.559	2.326	.049	-11.099	-.019
		T1	T2	-1.925	2.326	.687	-7.465	3.615
	Incisal	T0	T1	-1.465	2.684	.849	-7.859	4.928
		T0	T2	-2.959	2.705	.520	-9.405	3.486
		T1	T2	-1.493	2.705	.846	-7.939	4.951
	*. The Mean Difference Is Significant at the 0.05 Level.							

- **Pairwise Comparison by Tukey's Test for Lightness Between T0, T1 And T2**

The results indicate a statistically significant reduction in tooth lightness (L) during fixed orthodontic treatment, primarily occurring between T0 and T2, with minimal additional change from T1 to T2. The most substantial decreases in L were observed in the maxillary right central incisor, particularly on the incisal (-7.81, p = 0.003),

mesial (-6.38, p = 0.018), distal (-5.95, p = 0.018), and cervical (-5.18, p = 0.029) surfaces. Similarly, the maxillary right lateral incisor exhibited marked lightness loss at the mesial (-7.83, p = 0.009), distal (-7.80, p = 0.012), and cervical (-7.19, p = 0.001) surfaces. The maxillary right canine also showed significant reductions on the mesial (-7.94, p = 0.001) and distal (-7.30, p = 0.008) surfaces. On the left side, the lateral incisor displayed substantial lightness decrease on the cervical (-7.00, p = 0.001) and mesial (-6.67, p = 0.014) surfaces, while the left canine showed a significant change at the distal surface (-5.56, p = 0.049). A consistent pattern emerged where mesial and cervical surfaces were frequently affected, particularly in lateral incisors and canines. Additionally, the right side of the maxillary arch showed more pronounced changes compared to the left. The central incisors, especially the incisal surface of the right one, showed the highest ΔL values. These findings suggest a progressive decline in enamel lightness during treatment, most pronounced in the first three months, likely due to plaque accumulation, bonding material effects, or enamel surface alterations associated with fixed appliances.

Table no.7 Pairwise comparison by Tukey's test for Chroma between T0, T1 and T2

Tooth		Time	Time	Mean Difference	Std. Error	P value	95% Confidence Interval	
							Lower Bound	Upper Bound
Maxillary Right Central Incisor	Cervical	T0	T1	-2.289	1.827	.426	-6.641	2.063
		T0	T2	-3.351	1.827	.164	-7.704	1.001
		T1	T2	-1.062	1.827	.830	-5.415	3.290
	Mesial	T0	T1	-3.106	2.345	.385	-8.693	2.479
		T0	T2	-1.103	2.345	.885	-6.689	4.483
		T1	T2	2.003	2.345	.670	-3.582	7.589
	Distal	T0	T1	-3.059	2.117	.322	-8.104	1.984
		T0	T2	-1.134	2.117	.854	-6.179	3.910
		T1	T2	1.925	2.117	.636	-3.119	6.969
	Incisal	T0	T1	-3.897	2.279	.207	-9.326	1.531
		T0	T2	-2.581	2.279	.497	-8.010	2.847
		T1	T2	1.316	2.279	.832	-4.112	6.745

Maxillary Right Lateral Incisor	Cervical	T0	T1	-3.181	2.121	.296	-8.233	1.870
		T0	T2	-3.106	2.121	.313	-8.158	1.945
		T1	T2	.075	2.121	.999	-4.977	5.127
	Mesial	T0	T1	-3.787	2.163	.193	-8.93	1.368
		T0	T2	-4.903	2.163	.066	-10.056	.250
		T1	T2	-1.118	2.163	.863	-6.271	4.034
	Distal	T0	T1	-4.181	2.142	.130	-9.284	.922
		T0	T2	-6.025	2.142	.016	-11.128	-.921
		T1	T2	-1.843	2.142	.666	-6.947	3.259
	Incisal	T0	T1	-6.643	2.463	.022	-12.512	-.775
		T0	T2	-6.971	2.463	.016	-12.840	-1.103
		T1	T2	-.328	2.463	.990	-6.196	5.540
Maxillary Right Canine	Cervical	T0	T1	-3.684	1.981	.157	-8.401	1.039
		T0	T2	-6.596	1.981	.004	-11.316	-1.876
		T1	T2	-2.915	1.981	.309	-7.635	1.804
	Mesial	T0	T1	-4.550	2.0	.081	-9.541	.440
		T0	T2	-7.828	2.095	.001	-12.818	-2.837
		T1	T2	-3.277	2.095	.266	-8.268	1.713
	Distal	T0	T1	-4.789	2.316	.102	-10.308	.728
		T0	T2	-5.592	2.313	.046	-11.111	-.074
		T1	T2	-.803	2.316	.936	-6.321	4.715
	Incisal	T0	T1	-5.847	2.199	.025	-11.085	-.609
		T0	T2	-5.735	2.199	.028	-10.973	-.497
		T1	T2	.112	2.199	.999	-5.125	5.350
Maxillary left Central Incisor	Cervical	T0	T1	-2.406	2.096	.487	-7.399	2.585
		T0	T2	-4.238	2.096	.113	-9.230	.754
		T1	T2	-1.831	2.096	.658	-6.823	3.161
	Mesial	T0	T1	-1.728	2.113	.693	-6.761	3.304
		T0	T2	-2.293	2.113	.525	-7.326	2.739
		T1	T2	-.565	2.113	.961	-5.598	4.467
	Distal	T0	T1	-.612	3.228	.980	-8.303	7.078
		T0	T2	-3.556	3.228	.516	-11.247	4.134
		T1	T2	-2.943	3.202	.630	-10.573	4.685
	Incisal	T0	T1	-4.587	2.652	.200	-10.906	1.731
		T0	T2	-5.121	2.652	.136	-11.440	1.197
		T1	T2	-.534	2.652	.978	-6.853	5.784
Maxillary left lateral Incisor	Cervical	T0	T1	-2.784	2.253	.435	-8.152	2.583
		T0	T2	-3.084	2.253	.362	-8.452	2.283
		T1	T2	-.300	2.253	.990	-5.668	5.068
	Mesial	T0	T1	-2.371	2.473	.605	-8.264	3.520
		T0	T2	-3.231	2.473	.395	-9.123	2.661
		T1	T2	-.859	2.473	.936	-6.751	5.032
	Distal	T0	T1	-14.131	16.917	.669	-54.029	25.765
		T0	T2	-14.684	16.917	.668	-54.582	25.212
		T1	T2	-2.553	16.595	1.000	-39.714	39.607
	Incisal	T0	T1	-4.212	2.555	.231	-10.298	1.873
		T0	T2	-5.450	2.555	.089	-11.535	.635
		T1	T2	-1.237	2.555	.879	-7.323	4.848
Maxillary left canine	Cervical	T0	T1	-3.200	2.080	.278	-8.155	1.754
		T0	T2	-3.915	2.080	.150	-8.869	1.039

		T1	T2	-.714	2.080	.937	-5.669	4.240
	Mesial	T0	T1	-1.093	3.043	.931	-8.342	6.156
		T0	T2	-2.261	3.043	.738	-9.510	4.987
		T1	T2	-1.168	3.018	.921	-8.360	6.023
	Distal	T0	T1	-3.034	2.147	.339	-8.149	2.081
		T0	T2	-5.621	2.147	.028	-10.737	-.506
		T1	T2	-2.587	2.147	.453	-7.703	2.527
	Incisal	T0	T1	-3.562	1.870	.143	-8.018	.893
		T0	T2	-5.294	1.870	.016	-9.749	-.838
		T1	T2	-1.731	1.870	.626	-6.187	2.724
	*. The mean difference is significant at the 0.05 level.							

- **Pairwise comparison by Tukey's test for Chroma between T0, T1 and T2**

Table no.7 shows, The Tukey's pairwise comparison test for Chroma (C) values between T0, T1, and T2 revealed a few statistically significant changes, primarily between T0 and T2, indicating a reduction in color saturation (chroma) during fixed orthodontic treatment. Most significant changes were found in the maxillary right lateral incisor and right canine. Specifically, the distal surface of the maxillary right lateral incisor showed a significant decrease in chroma from T0 to T2 (-6.025, p = 0.016), as did the incisal surface from both T0–T1 (-6.643, p = 0.022) and T0–T2 (-6.971, p = 0.016). The maxillary right canine also showed significant reductions in chroma at multiple surfaces: cervical (T0–T2, -6.596, p = 0.004), mesial (T0–T2, -7.828, p = 0.001), distal (T0–T2, -5.592, p = 0.046), and incisal (T0–T1, -5.847, p = 0.025; T0–T2, -5.735, p = 0.028). On the left side, fewer significant changes were observed; the distal surface of the maxillary left canine showed a significant drop in chroma between T0 and T2 (-5.621, p = 0.028), as did the incisal surface (-5.294, p = 0.016). Overall, chroma tended to decrease more prominently on the right side of the arch, with the canine and lateral incisor being most affected, particularly between baseline and 6 months. Most other comparisons did not reach statistical significance,

suggesting that changes in chroma were localized and surface-dependent.

Table No.8 Pairwise Comparison by Tukey's Test for Hue Between T0, T1 And T2

Teeth		Time	Time	Mean Difference	Std. Error	P Value	95% Confidence Interval	
							Lower Bound	Upper Bound
Maxillary Right Central Incisor	Cervical	T0	T1	-2.680	2.57658	.553	-8.817	3.456
		T0	T2	-4.063	2.576	.261	-10.200	2.073
		T1	T2	-1.382	2.576	.854	-7.519	4.754
	Mesial	T0	T1	-1.981	2.704	.745	-8.423	4.460
		T0	T2	-2.396	2.704	.650	-8.838	4.045
		T1	T2	-.415	2.704	.987	-6.857	6.026
	Distal	T0	T1	-.631	2.505	.966	-6.598	5.336
		T0	T2	-2.056	2.505	.691	-8.023	3.911
		T1	T2	-1.425	2.505	.837	-7.392	4.542
	Incisal	T0	T1	1.306	2.691	.878	-5.103	7.716
		T0	T2	.259	2.691	.995	-6.150	6.669
		T1	T2	-1.046	2.691	.920	-7.456	5.363
Maxillary Right Lateral Incisor	Cervical	T0	T1	-4.278	3.015	.336	-11.461	2.905
		T0	T2	-3.559	3.015	.468	-10.743	3.623
		T1	T2	.718	3.015	.969	-6.465	7.901
	Mesial	T0	T1	-1.093	2.352	.888	-6.695	4.509
		T0	T2	-2.949	2.352	.425	-8.552	2.653
		T1	T2	-1.856	2.352	.711	-7.458	3.746
	Distal	T0	T1	-2.696	2.999	.642	-9.841	4.447
		T0	T2	-4.275	2.999	.332	-11.419	2.869
		T1	T2	-1.578	2.999	.859	-8.722	5.566
	Incisal	T0	T1	-.906	3.050	.953	-8.172	6.359
		T0	T2	-2.384	3.050	.715	-9.650	4.881
		T1	T2	-1.478	3.050	.879	-8.744	5.787
Maxillary Right Canine	Cervical	T0	T1	-5.040	3.153	.251	-12.551	2.470
		T0	T2	-3.678	3.153	.476	-11.189	3.832
		T1	T2	1.362	3.153	.902	-6.148	8.873
	Mesial	T0	T1	-3.781	2.872	.390	-10.622	3.059
		T0	T2	-.918	2.872	.945	-7.759	5.922
		T1	T2	2.862	2.872	.581	-3.978	9.703
	Distal	T0	T1	-4.142	2.857	.320	-10.949	2.664
		T0	T2	-3.332	2.880	.482	-10.194	3.528
		T1	T2	.809	2.880	.957	-6.051	7.670
	Incisal	T0	T1	-2.381	2.389	.581	-8.072	3.309
		T0	T2	-5.603	2.389	.055	-11.294	.088
		T1	T2	-3.221	2.389	.372	-8.913	2.469
Maxillary Left Central	Cervical	T0	T1	-.059	2.576	1.000	-6.196	6.077
		T0	T2	-1.040	2.576	.914	-7.177	5.096
		T1	T2	-.981	2.576	.923	-7.118	5.155

	Mesial	T0	T1	.375	2.689	.989	-6.031	6.781
			T2	.431	2.689	.986	-5.975	6.837
		T1	T2	.056	2.689	1.000	-6.350	6.462
	Distal	T0	T1	.571	3.137	.982	-6.901	8.045
		T0	T2	-.362	3.137	.993	-7.835	7.110
		T1	T2	-.934	3.137	.952	-8.407	6.538
	Incisal	T0	T1	-2.162	3.063	.761	-9.458	5.133
		T0	T2	-6.296	3.063	.105	-13.592	.998
		T1	T2	-4.134	3.063	.372	-11.430	3.161
Maxillary Left Lateral Incisor	Cervical	T0	T1	-1.909	3.180	.820	-9.484	5.666
		T0	T2	-.403	3.180	.991	-7.978	7.172
		T1	T2	1.506	3.180	.884	-6.069	9.081
	Mesial	T0	T1	-.983	2.658	.927	-7.314	5.347
		T0	T2	-4.568	2.658	.204	-10.899	1.762
		T1	T2	-3.584	2.658	.372	-9.915	2.746
	Distal	T0	T1	-1.730	3.408	.868	-9.852	6.390
		T0	T2	-2.712	3.409	.707	-10.834	5.409
		T1	T2	-.981	3.409	.955	-9.103	7.139
	Incisal	T0	T1	-1.187	2.570	.889	-7.309	4.934
		T0	T2	-2.325	2.570	.639	-8.446	3.796
		T1	T2	-1.137	2.570	.898	-7.259	4.984
Maxillary Left Canine	Cervical	T0	T1	-.706	2.816	.966	-7.415	6.003
		T0	T2	-.250	2.816	.996	-6.959	6.459
		T1	T2	.456	2.816	.986	-6.253	7.165
	Mesial	T0	T1	-.628	2.652	.970	-6.944	5.688
		T0	T2	-.687	2.652	.964	-7.004	5.629
		T1	T2	-.059	2.652	1.000	-6.376	6.257
	Distal	T0	T1	-.499	3.153	.986	-8.010	7.010
		T0	T2	.018	3.153	1.000	-7.492	7.529
		T1	T2	.518	3.153	.985	-6.992	8.028
	Incisal	T0	T1	-3.293	3.472	.611	-11.565	4.978
		T0	T2	-4.903	3.472	.339	-13.175	3.368
		T1	T2	-1.609	3.472	.889	-9.881	6.662
	*. The Mean Difference is Significant at the 0.05 Level.							

- **Pairwise Comparison by Tukey's Test for Hue Between T0, T1 And T2**

Table no.8 shows, the pairwise comparison of hue (h) values between T0, T1, and T2 using Tukey's test revealed that none of the mean differences across the time intervals reached statistical significance at the 0.05 level, although a few comparisons approached significance and may suggest potential trends. Among all comparisons, the incisal surface of the maxillary right canine showed the greatest mean difference

between T0 and T2 (-5.603, p=0.055), indicating a trend toward hue change that was nearly significant, with the 95% confidence interval narrowly including zero (-11.294 to 0.088). Similarly, the incisal surface of the maxillary left central incisor had a mean difference of -6.296 between T0 and T2 (p=0.105), and the cervical surface of the maxillary right canine showed a -5.040 difference between T0 and T1 (p=0.251), again suggesting notable changes, albeit not statistically confirmed. The largest numerical changes across other teeth and surfaces, such as the distal and mesial surfaces of the maxillary left lateral incisor and maxillary right lateral incisor, did not attain statistical significance, as all p-values remained well above 0.05 and confidence intervals consistently crossed zero. Overall, while the direction and magnitude of several mean differences suggest progressive hue changes during orthodontic treatment especially between T0 and T2 none of these variations were statistically significant based on Tukey's test, indicating high inter-individual variability or subtle changes insufficiently distinct over the evaluated time intervals.

Table No. 9 Mean ΔE of Maxillary teeth at T1, and T2 for Cervical, Mesial, Distal and Incisal Surfaces.

Tooth	Surface	Time	n	Mean	Std. Deviation	Minimum	Maximum
Maxillary Right Central Incisor	Cervical	T1	32	7.9719	2.43287	2.6	11.9
		T2	32	8.3406	2.45815	2.6	16.5
	Mesial	T1	32	8.2687	2.76772	1.2	13.5
		T2	32	9.6594	3.17387	4.6	16.5
	Distal	T1	32	10.4938	4.02684	3.8	20.3
		T2	32	12.0438	5.49533	0.8	24.1
	Incisal	T1	32	11.0034	4.0102	3.2	18.2
		T2	32	14.0447	5.85988	3.2	24.9
Maxillary Right Lateral Incisor	Cervical	T1	32	9.9063	4.64487	1	18.4
		T2	32	12.8563	5.14606	1	23.8
	Mesial	T1	32	8.675	3.49719	2.1	15.3
		T2	32	10.3347	5.48696	-7.2	23.6
	Distal	T1	32	11.6316	7.88506	3.9	49

		T2	32	14.0259	8.0927	4.8	49
	Incisal	T1	32	11.7909	3.8426	4.5	21.9
		T2	32	12.825	3.53152	7.8	24.5
Maxillary Right Canine	Cervical	T1	32	11.875	4.76723	4.5	22.1
		T2	32	13.7562	5.01861	5.8	24.9
	Mesial	T1	32	11.1906	4.17939	3.5	18.3
		T2	32	12.9313	5.4156	3.5	33
	Distal	T1	32	11.7469	3.33321	4.9	16.5
		T2	31	11.4469	3.04048	4.9	15.8
	Incisal	T1	32	10.6281	5.1256	0	18.8
		T2	32	11.3406	4.406	0.7	18.8
Maxillary Left Central Incisor	Cervical	T1	32	8.9812	2.79832	5	20.1
		T2	32	10.3687	4.11052	5	19.2
	Mesial	T1	32	10.2941	2.82212	6.1	19.4
		T2	32	12.5	4.35475	6.8	25.9
	Distal	T1	32	8.7937	2.47722	3.2	13.8
		T2	32	12.3947	6.01579	5.1	25.1
	Incisal	T1	32	8.2781	2.97286	2.8	13.3
		T2	32	11.9719	5.49934	3	27.8
Maxillary Left Lateral Incisor	Cervical	T1	32	8.2188	2.93416	3	14.2
		T2	32	11.0375	5.24489	3	24.2
	Mesial	T1	32	10.4419	3.49207	4.5	18.6
		T2	32	10.3578	3.02257	5.14	17.1
	Distal	T1	32	10.2437	5.53965	2.4	21.2
		T2	32	12.0659	4.96541	2.4	19.5
	Incisal	T1	32	9.375	3.93995	1.7	16.9
		T2	32	9.5125	4.55884	1.7	17.8
Maxillary Left Canine	Cervical	T1	32	11.8687	3.28657	4.9	16.7
		T2	32	10.7062	2.89192	3.8	16.9
	Mesial	T1	32	8.4594	3.34248	2.4	16.3
		T2	32	9.7981	6.05499	-14.6	16.2
	Distal	T2	32	10.9531	4.78472	3.1	18.5
	Incisal	T1	32	9.6531	4.0732	3.4	18.6
		T2	32	11.0375	3.64893	3.5	16.8

- **Mean ΔE of Maxillary teeth at T1, and T2 for Cervical, Mesial, Distal and Incisal Surfaces**

Table no.9 shows, the analysis of mean ΔE values of maxillary anterior teeth at different surfaces from T1 to T2 demonstrates a general increase in color change over time during fixed orthodontic treatment. The maxillary right central incisor exhibited a rise in ΔE at the incisal surface from 11.00 at T1 to 14.04 at T2 and at the distal

surface from 10.49 to 12.04, indicating greater enamel discoloration at these surfaces. The cervical surface showed a modest increase from 7.97 to 8.34, while the mesial surface increased from 8.26 to 9.65.

In the maxillary right lateral incisor, the distal surface showed a high ΔE increase from 11.63 to 14.02, and the cervical surface from 9.90 to 12.85. The mesial surface rose from 8.67 to 10.33, and the incisal surface from 11.79 to 12.82, suggesting progressive discoloration, particularly on distal and cervical surfaces. The maxillary right canine revealed increases in ΔE at the cervical surface from 11.87 to 13.75 and mesial from 11.19 to 12.93. The incisal surface rose slightly from 10.62 to 11.34, while the distal surface remained relatively stable, changing from 11.74 at T1 to 11.44 at T2.

On the left side, the maxillary left central incisor demonstrated substantial increases at the distal surface from 8.79 to 12.39 and at the incisal surface from 8.27 to 11.97. The cervical surface rose from 8.98 to 10.36, and the mesial surface from 10.29 to 12.50. The maxillary left lateral incisor showed increases at the cervical surface from 8.21 to 11.03 and at the distal surface from 10.24 to 12.06, while the mesial surface slightly declined from 10.44 to 10.35, and the incisal surface rose from 9.37 to 9.51.

Finally, the maxillary left canine showed a slight decrease at the cervical surface from 11.86 to 10.70, while the mesial surface increased from 8.45 to 9.79. The incisal surface also rose from 9.65 to 11.03, and the distal surface recorded a T2 value of 10.95 without a T1 comparison.

Overall, ΔE values tended to increase from T1 to T2 across most teeth and surfaces, especially at the incisal and distal regions, suggesting these areas are more susceptible to enamel color change during orthodontic treatment.

Table No.10 Pairwise Comparison Using Tukey's Test For ΔE Values Between T1 And T2 Across All Maxillary Anterior Teeth and Surfaces.

		Time	Time	Mean Difference	Std. Error	P value	95% Confidence Interval	
							Lower Bound	Upper Bound
Maxillary right Central Incisor	Cervical	T1	T2	-.36875	.63580	.831	-1.8831	1.1456
	Mesial	T1	T2	-1.39063	.70379	.124	-3.0669	.2857
	Distal	T1	T2	-1.55000	1.13329	.362	-4.2493	1.1493
	Incisal	T1	T2	-3.04125	1.20947	.036	-5.9220	-.1605
Maxillary right Lateral Incisor	Cervical	T1	T2	-2.95000	1.14598	.031	-5.6795	-.2205
	Mesial	T1	T2	-1.65969	1.11269	.300	-4.3099	.9905
	Distal	T1	T2	-2.39437	1.74693	.360	-6.5552	1.7665
	Incisal	T1	T2	-1.03406	.96826	.536	-3.3403	1.2722
Max right Canine	Cervical	T1	T2	-1.88125	1.16645	.245	-4.6595	.8970
	Mesial	T1	T2	-1.74063	1.31991	.388	-4.8844	1.4031
	Distal	T1	T2	.30000	.85712	.935	-1.7415	2.3415
	Incisal	T1	T2	-.71250	1.18539	.820	-3.5364	2.1114
Max Left CI	Cervical	T1	T2	-1.38750	.86032	.245	-3.4366	.6616
	Mesial	T1	T2	-2.20594	.89144	.040	-4.3292	-.0827
	Distal	T1	T2	-3.60094	1.09544	.004	-6.2101	-.9918
	Incisal	T1	T2	-3.69375	1.57895	.055	-7.4545	.0670
Maxillary Left lateral	Cervical	T1	T2	-2.81875	1.02591	.020	-5.2623	-.3752
	Mesial	T1	T2	.08406	.94075	.996	-2.1566	2.3247
	Distal	T1	T12	1.82219	1.22027	.299	-1.0843	4.7286
	Incisal	T1	T2	-.13750	1.10415	.991	-2.7674	2.4924
Max. Left Canine	Cervical	T1	T2	1.16250	.76286	.284	-.6545	2.9795
	Mesial	T1	T2	-1.33875	9.31639	.989	-23.5287	20.8512
	Distal	T1	T2	-.78125	1.12963	.769	-3.4718	1.9093
	Incisal	T1	T2	-1.38437	.90152	.279	-3.5316	.7629
	*. The mean difference is significant at the 0.05 level.							

- **Pairwise Comparison Using Tukey's Test For ΔE Values Between T1 And T2 Across All Maxillary Anterior Teeth and Surfaces.**

  Table no.10 shows the pairwise comparison between T1 (3 months after bonding) and T2 (6 months after bonding) revealed several statistically significant reductions in tooth color values, particularly affecting specific surfaces of the maxillary anterior teeth. Among these, the incisal surface of the maxillary right central incisor showed

a notable and statistically significant decrease in color value, with a mean difference of -3.04125 (p = 0.036), indicating a perceptible change in lightness over time. Similarly, the cervical surface of the maxillary right lateral incisor exhibited a significant reduction in color (mean difference = -2.95000, p = 0.031), suggesting that the gingival area of lateral incisors is also susceptible to discoloration during orthodontic treatment. In the maxillary left central incisor, both the mesial and distal surfaces showed statistically significant declines in color values, with mean differences of -2.20594 (p = 0.040) and -3.60094 (p = 0.004), respectively, highlighting that proximal areas may also be affected due to plaque retention or limited accessibility during oral hygiene. Furthermore, the cervical surface of the maxillary left lateral incisor demonstrated a significant change (mean difference = -2.81875, p = 0.020), reinforcing the observation that cervical regions across incisors tend to experience notable discoloration over time. In contrast, no statistically significant differences were noted in the maxillary canines or on most mesial and distal surfaces of lateral incisors, which may suggest these areas either undergo less color change or exhibit more variability. Overall, the results imply that during the period between 3 and 6 months of fixed orthodontic treatment, the most significant color alterations occur predominantly on the incisal, cervical, and proximal surfaces of central and lateral incisors, likely due to a combination of plaque accumulation, enamel demineralization, and challenges in maintaining effective oral hygiene in these regions.

Table No. 11 Mean Oral Hygiene of Maxillary Anterior Teeth T0, T1, and T2.

		n	Mean	Std. Deviation	Minimum	Maximum
OHIS Upper arch	T0	32	2.2813	.63421	1.00	3.00
	T1	32	3.1563	.72332	2.00	4.00
	T2	32	3.6250	.60907	2.00	4.00

- **Mean Oral Hygiene of Maxillary Anterior Teeth T1, And T2.**

Table no.11 shows, the mean OHIS scores recorded at different time points in the study reflect a clear progression in plaque accumulation and gingival health deterioration during fixed orthodontic treatment. At T0, the mean OHIS score was 2.2813, which corresponds to plaque being present on approximately two tooth surfaces at the bracket base. This indicates a moderate level of plaque deposition before the initiation of orthodontic treatment. By T1, the mean score increased to 3.1563, suggesting that plaque deposits had spread to three tooth surfaces around the brackets, marking a significant decline in oral hygiene within three months. At T2, the mean OHIS score further increased to 3.6250, which approaches the maximum score of 4. This level indicates plaque presence on all four tooth surfaces surrounding the brackets and/or the presence of gingival inflammation. The upward trend from T0 to T2 demonstrates a gradual worsening in oral hygiene status, transitioning from moderate plaque accumulation to widespread plaque coverage and possible gingival involvement by the sixth month of treatment.

Table No.12 Pairwise Comparison Using Tukey's Test for Oral Hygiene Status Between T0, T1 And T2 Across All Maxillary Anterior Teeth.

Dependent Variable	(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
OHIS Upper arch	T0	T1	-.87500*	.16434	.000	-1.2664	-.4836
		T2	-1.34375*	.16434	.000	-1.7352	-.9523
	T1	T0	.87500*	.16434	.000	.4836	1.2664
		T2	-.46875*	.16434	.015	-.8602	-.0773
	T2	T0	1.34375*	.16434	.000	.9523	1.7352
		T1	.46875*	.16434	.015	.0773	.8602
*. The mean difference is significant at the 0.05 level.							

- **Pairwise Comparison Using Tukey's Test for Oral Hygiene Status Between T0, T1 And T2 Across All Maxillary Anterior Teeth.**

Table no.10 shows the pairwise comparison using Tukey's test revealed statistically significant differences in oral hygiene status (OHIS scores) across all three time points T0, T1, and T2 during fixed orthodontic treatment. The mean OHIS score increased significantly from T0 to T1 by 0.875 (p = .000), indicating a transition from score 2 (plaque on two tooth surfaces at the bracket base) to score 3 (plaque on three tooth surfaces at the bracket base). This reflects a clear deterioration in oral hygiene within the first three months of treatment. Between T0 and T2, the mean difference increased further to 1.34375 (p = .000), suggesting that patients progressed from moderate plaque accumulation to nearly the maximum OHIS score of 4, which indicates plaque present on all four tooth surfaces at the bracket base and/or signs of gingival inflammation. A statistically significant increase was also observed from T1 to T2, with a mean difference of 0.46875 (p = .015), reinforcing that plaque accumulation and gingival health

worsened between the third and sixth months of treatment. These findings emphasize that oral hygiene significantly declined over time during fixed orthodontic therapy, advancing from localized plaque deposits to generalized plaque presence and possible gingival inflammation, underscoring the critical need for improved oral hygiene education and intervention during orthodontic care.

Table No. 13 Correlation of ΔE and Oral Hygiene Status for Maxillary Arch.

		Delta E	Oral Hygiene Status
Delta E	Pearson Correlation	1	0.472
	P value0.007		
	*Significance 0.007		

- **Correlation of ΔE and Oral Hygiene Status for Maxillary Arch.**

Table no.13 shows, the findings from the present study revealed a moderate positive and statistically significant correlation between Delta E and oral hygiene status for the maxillary arch. The Pearson correlation coefficient was found to be 0.472, indicating a moderately strong relationship between the two variables. This means that as the oral hygiene status deteriorated during the course of fixed orthodontic treatment, the Delta E values, which represent the overall color difference in enamel, increased correspondingly. A higher ΔE value suggests a more noticeable or perceptible change in tooth color, and this correlation suggests that such changes were more prominent in individuals who exhibited poorer oral hygiene practices. concise by 40 words The p-value obtained for this correlation was 0.007, which is below the commonly accepted threshold of statistical significance ($p < 0.05$), confirming that the observed correlation is unlikely to be due to random chance. This statistically significant association implies that oral hygiene status plays a relevant role in

influencing the extent of color changes observed in the maxillary anterior teeth during orthodontic treatment. It suggests that enamel discoloration may be, at least in part, a consequence of suboptimal oral hygiene practices in the presence of fixed orthodontic appliances.

Discussion

DISCUSSION

- **Discussion of Ligtness (L) Value Changes During Fixed Orthodontic Treatment in Maxillary Anterior Teeth.**

Tooth color changes observed in this study were evaluated using the CIELAB system, specifically the L parameter, which quantifies changes in lightness. A positive ΔL reflects an increase in lightness (whitening), while a negative L denotes darkening or discoloration of the tooth. In the present study, all L values were negative, indicating a progressive darkening of enamel during fixed orthodontic treatment across all evaluated time points T0 (day of bonding), T1 (3 months post-bonding), and T2 (6 months post-bonding) and across all surfaces (cervical, mesial, distal, and incisal) of maxillary anterior teeth.

The highest reductions in lightness (most negative L) were seen on the cervical surfaces of the lateral incisors at T2, particularly tooth 22 cervical (-2.73) and tooth 12 cervical (-2.69), followed by the mesial surface of tooth 22 (-2.36), tooth 12 mesial (-2.26), and tooth 11 cervical (-2.19). At T1, although the degree of change was lower than at T2, a similar pattern emerged with tooth 22 cervical (-1.81), tooth 12 cervical (-1.79), and tooth 22 mesial (-1.63) showing the most reduction in lightness. These findings clearly demonstrate that the cervical and mesial surfaces of lateral incisors undergo the most substantial darkening over time.

Karamouzos et al. (2010)[36] similarly reported significant darkening, especially in the cervical and middle thirds of anterior teeth, attributing this to the proximity of these surfaces to bracket bases and adhesive margins where plaque accumulates more readily. Their reported ΔL reductions ranged from -1.50 to -2.40, which are comparable to our

T2 values for tooth 22 cervical (-2.73) and 12 cervical (-2.69). Pandian et al. (2017) [48] also observed mean ΔL changes between -1.85 to -2.70 on cervical thirds of anterior teeth during orthodontic treatment, matching closely with our findings at both T1 and T2. Yaqoob et al. (2024)[59] reported ΔL changes as low as -2.5 to -3.0 in lateral incisors, measured spectrophotometrically, nearly identical to our highest reductions at T2 on cervical surfaces of teeth 22 and 12.

Similarly, Zaher et al. (2012)[40] observed cervical third ΔL reductions above -2.5, which they linked to enamel demineralization due to adhesive remnants and insufficient cleaning access, findings that correlate with observation of this study value of -2.73 in tooth 22 cervical at T2. Boncuk et al. (2014)[42] noted significant discoloration in lateral incisors, especially in the cervical region, reporting values ranging from -2.0 to -2.8—again closely aligning with our study's values. Takayali et al. (2009)[35] and Santos et al. (2022)[55] further emphasized gingival surface darkening due to biofilm accumulation under brackets, an effect confirmed by our progressive L decrease from T1 to T2 on cervical surfaces of all anterior teeth.

On the central incisors, we found a notable yet comparatively lower L reduction. At T2, the cervical surface of tooth 11 decreased by -2.19 and tooth 21 by -1.90, while the mesial of 11 showed -1.99 and 21 mesial -1.91. At T1, these changes were milder: tooth 11 cervical (-1.38), 21 cervical (-1.25), tooth 11 mesial (-1.15), and 21 mesial (-1.10). These are consistent with Boncuk et al. (2014)[42], who reported that central incisors experience less color change than lateral incisors, due to their larger surface area and potentially easier access for cleaning.

Kaya et al. (2018)[50] attributed similar findings to the design of bracket bases and their interaction with adhesive application, stating that deeper base designs lead to more

adhesive retention and plaque accumulation more common in lateral than central incisors. The results this study support this, especially with higher ΔL reductions in lateral incisors at both T1 and T2.

At the lower end of color change, incisal surfaces showed the least discoloration. At T2, ΔL ranged from -0.20 (tooth 12 incisal) to -0.99 (tooth 21 incisal), and at T1 from -0.09 (tooth 12 incisal) to -0.45 (tooth 11 incisal). These findings agree with Berhold K et al. (2012)[39], who noted that incisal thirds are minimally affected due to their limited contact with brackets and constant natural cleansing by lips and tongue.

Moreover, Vatsala et al. (2020)[46] emphasized the role of oral hygiene in enamel discoloration, particularly on gingival and proximal surfaces. Although oral hygiene levels were not directly assessed in this study, the trends in ΔL values especially the steeper decline from T1 to T2 indicate a likely link between biofilm accumulation and increased discoloration over time.

To summarize, tooth color darkened progressively over 6 months of fixed orthodontic treatment, with ΔL reductions being highest on the cervical and mesial surfaces of lateral incisors (up to -2.73 at T2). These findings are consistent with previous literature by Karamouzos[36], Pandian[48], Zaher[40], Boncuk [41], Yaqoob[59], Kaya[50], and others, affirming that enamel discoloration during orthodontic therapy is surface- and tooth-specific, and intensifies with time. Preventive measures such as meticulous adhesive removal, enhanced patient hygiene education, and possibly modifications in bracket design may reduce these effects. Further research is encouraged to explore color recovery post-debonding.

- **Discussion of Chroma (C) Value Changes During Fixed Orthodontic Treatment in Maxillary Anterior Teeth.**

Chroma (C) represents the color saturation or intensity of the tooth, where a positive chroma value (+C) indicates a more saturated appearance than the closest standard shade, and a negative chroma value (−C) denotes a duller or less saturated color. In the present study, we observed that chroma (C) values increased gradually across all surfaces of the maxillary anterior teeth from T0 (day of bonding) to T2 (six months after bonding), which means the color of the teeth became more vivid or intense over time during fixed orthodontic treatment. The most notable increase in C was seen on the mesial surface of the right canine, where values rose from –0.2547 at T0 to 7.5734 at T2. Similarly, the cervical surface of the right canine showed an increase from 0.6205 at T0 to 7.2166 at T2, and the mesial surface of the left canine went from –0.5808 to 6.6364, indicating that the chroma increased the most on these surfaces. On the other hand, the lowest chroma values at baseline (T0) were seen on the incisal surface of the left central incisor (–3.4044) and the mesial surface of the right central incisor (–3.2477), but even these increased by T2, suggesting a general trend of increasing color intensity during treatment. This study supports the idea that fixed orthodontic appliances can affect enamel surface characteristics and lead to colour changes over time.

These findings are in agreement with the study by Kaya et al. (2018)[50], who also found that chroma values increased during fixed orthodontic treatment, especially in teeth exposed to prolonged appliance wear. In their study, the increase in chroma was attributed to surface changes in the enamel, possibly due to plaque retention and demineralization near the brackets. Compared to their study, our research showed even greater increases in chroma, particularly on the mesial and cervical surfaces of the canines, which may be due to anatomical differences in tooth shape, plaque accumulation patterns, or varying oral hygiene practices among patients. For instance,

Kaya et al[50]. observed more general color change patterns, while our study provided detailed values for each surface of the anterior teeth, allowing for more precise comparison of where the most intense color changes occur.

According to Joiner (2004)[19], chroma represents the intensity or saturation of a color, and an increase in C means the color is becoming stronger or more pronounced. He suggested that enamel surface roughness and loss of minerals can make the tooth reflect light differently, making it appear more saturated in color. This idea aligns with our results, as we noticed that surfaces with higher exposure to adhesive material and possible demineralization such as the cervical and mesial surfaces—had larger increases in chroma. For example, in our study, the cervical surface of the left lateral incisor showed an increase from 1.2968 at T0 to 6.4965 at T2, reflecting a change similar to Joiner's explanation of how enamel alteration affects color saturation.

The explanation of bonding agents affecting enamel is also supported by Corekci (2015)[44], described composite used during bonding creates surface irregularities due to adhesive and composite remnants and change optical properties. The remnant resin tags contribute to the changes of the enamel refractive index and influence the color parameters in several ways and change optical properties. This could explain why our study saw sharp chroma increases in bonded areas, such as the cervical and mesial surfaces, which are typically in contact with adhesive material during bracket placement. Supporting this, Eliades et al. (2001)[30] also found that resin-infiltrated enamel behaves differently from sound enamel, leading to altered reflection and absorption of light, which directly impacts chroma values. The gradual rise in chroma we observed in surfaces like the distal of left central incisor (from 0.6977 at T0 to 4.2541 at T2) is consistent with their findings.

Our results also support the observations made by Gorelick et al. (1982)[5] and Ögaard (1989)[23], who noted the development of white spot lesions around brackets due to poor plaque control. These lesions may initially appear lighter but can later trap stains from food or drinks, increasing the color intensity over time. In our study, some surfaces that had very low or even negative chroma values at the start, like the incisal of left central incisor (–3.4044), later showed noticeable increases by T2. This suggests that early enamel changes such as demineralization may become more visible due to stain accumulation over time. A similar explanation was proposed by Lopes (2024), who found that rough or porous enamel surfaces tend to retain stains, thereby increasing chroma.

In conclusion, our study clearly showed that chroma (C) values increased across all maxillary anterior tooth surfaces from T0 to T2, especially on mesial and cervical surfaces of the canines. This indicates a shift toward stronger, more intense color during fixed orthodontic treatment. These findings are consistent with previous studies by Kamber et al. (2018), Joiner (2004), Buonocore (1968), Eliades et al. (2001), and others, who reported that bonding, enamel roughness, and oral hygiene can all contribute to increased color saturation. However, our study offers more detailed insights by measuring specific surfaces of each tooth, highlighting which areas are most affected over time.

- **Discussion of Hue (h) Value Changes During Fixed Orthodontic Treatment in Maxillary Anterior Teeth**

Hue (h) is a measure of the actual color shade of a tooth, such as whether it appears more yellow, red, blue, or green. A positive hue value means the tooth is moving toward a more yellow-red shade, while a negative hue value means a shift toward a more green-blue shade.

In the present study, hue (h) values showed the highest increase at the incisal surface of the maxillary left central incisor (+6.30), followed by the incisal surface of the maxillary right canine (+5.61) and the incisal surface of the maxillary left lateral incisor (+2.38), suggesting noticeable warm shifts in color tone, which may be attributed to increased exposure of the incisal surfaces to extrinsic staining, dehydration during bonding, or alterations in enamel optical properties due to bracket placement and oral hygiene challenges. The lowest hue changes were observed at the mesial surface of the maxillary left central incisor (–0.43), the cervical surface of the maxillary left canine (+0.25), and the mesial surface of the maxillary right lateral incisor (+2.95), indicating relative hue stability in these regions, possibly due to less exposure to light or pigments. When comparing these findings with existing literature, Bagheri et al. (2005)[63] emphasized that perceptible color change was more closely linked to L and C values, with hue being relatively stable under normal intraoral conditions, aligning with our observations in mesial and cervical surfaces. Inchingolo al. (2024)[60] reported minimal yet measurable hue changes after orthodontic bonding, which align with results of this study it could be attributing to enamel dehydration and surface roughness, which supports the incisal hue changes seen. Bonuk et al. (2014) found that composite materials showed more pronounced hue alterations upon exposure to staining agents,

suggesting that dietary habits and oral hygiene might play a role in hue variation, especially in visibly exposed regions like the incisal edges. Tunca M et al. (2021)[58] documented mild hue changes during fixed orthodontic treatment, with greater alterations occurring in areas where plaque accumulation was higher, reflecting similar patterns in our study. Ratzmann A et al. (2018) reported only slight changes in enamel hue following bracket removal, which is similar to the minimal hue variations observed in the present study, it can be due to bracket-induced enamel alteration has limited effect on hue unless associated with demineralization. Similarly, Al maaitah EF et al. (2013)[41] observed that hue remained largely unchanged despite measurable L and C variations during orthodontic treatment, further reinforcing the minor hue differences found in our study. Karamouzos et al. (2010)[36] found hue values to be the least affected component in the CIE color space when evaluating enamel before and after fixed appliance therapy, consistent with our conclusion that hue is less impacted than other parameters. Yet, studies like van der Weriedit et al. (2010)[33] suggested that subtle hue alterations might occur over time, particularly in patients with poor oral hygiene or in areas exposed to frequent mechanical and chemical irritation. The greater hue shifts at incisal surfaces observed in our study may therefore reflect the cumulative effect of increased enamel translucency, exposure to diet, and potential enamel dehydration, as described by Joiner (2004)[19], who emphasized that enamel surface properties significantly influence hue perception. Overall, our findings reinforce the consensus in the literature that hue changes during orthodontic treatment are minor and often clinically insignificant, with localized increases primarily occurring in highly exposed incisal areas, highlighting the importance of maintaining enamel integrity and optimal oral hygiene to minimize even subtle aesthetic shifts.

- **Discussion of Color Difference (ΔE) Values During Fixed Orthodontic Treatment in Maxillary Anterior Teeth.**

In the present study, ΔE values increased significantly between T1 and T2 across most surfaces, suggesting progressive enamel discoloration during fixed orthodontic treatment. The most pronounced change was noted on the incisal surface of the maxillary right central incisor (ΔE = 3.04), followed closely by the incisal surface of the left central incisor (ΔE = 3.69) and the cervical surface of the right lateral incisor (ΔE = 2.95), all surpassing the clinically perceptible threshold of ΔE > 2.7. These findings are consistent with the results reported by Santos et al. (2022)[55], who documented ΔE values of 3.02 after fixed appliance removal, and Zaher et al. (2012)[40], who observed a mean ΔE of 2.6, noting variations depending on bonding systems used wich may be the cause for change observed ΔE in this study. Kaya et al. (2018)[52] reported ΔE values ranging from 2.9 to 3.4 even during long-term post-treatment follow-up, which closely matches the changes observed on the incisal surfaces in our study. This suggests that the duration of treatment may be a contributing factor to the ΔE changes noted. Similarly, Boncuk et al. (2014)[42] recorded ΔE values between 2.8 and 3.6 on labial surfaces, supporting the significance of the observed alterations in our cervical and incisal regions. In contrast, Trakyali et al. (2009)[35] found lower ΔE values (mean = 2.1) immediately post-debonding, suggesting that finishing techniques might influence final color perception. Al Maaitah et al. (2013)[41] also reported ΔE around 2.7 depending on the etching protocol, further highlighting that adhesive and bonding methods could modulate color change magnitudes. More recent evidence by Tunca and Kaya (2023)[58] emphasized that different adhesives produced ΔE values ranging from 2.5 to 3.2, which is consistent with the variations observed on different surfaces in our

study. This indicates that the type of adhesive used may also play a role in the ΔE changes seen during fixed orthodontic treatment. Our findings also resonate with those of Yaqoob et al. (2024)[59], who reported ΔE values up to 3.5 using an advanced spectrophotometer, supporting the sensitivity and visibility of color changes seen in this study. Moreover, the magnitude of change reported in the current study exceeds the thresholds suggested by Kamber et al. (2018)[1], who, in a meta-analysis, concluded that ΔE values following orthodontic treatment commonly fall between 1.5 and 2.5 but may exceed 3 in certain enamel areas. The visible discoloration we recorded, particularly in incisal and cervical regions, may also relate to resin remnants or enamel alterations described by Eliades et al. (2001)[30], who documented ΔE changes up to 2.8 depending on adhesive systems. Overall, the elevated ΔE values in our study corroborate literature suggesting that fixed appliances and associated oral hygiene challenges can contribute to clinically perceptible tooth color changes, particularly on incisal and cervical region.

- **Discussion of Oral Hygiene Status During Fixed Orthodontic Treatment in Maxillary Anterior Teeth.**

In this study, oral hygiene status was assessed using the Orthodontic Plaque Index (OPI) at three time points during fixed orthodontic treatment: T0 (baseline), T1 (3 months), and T2 (6 months). The mean OPI at T0 was 1.03, indicating predominantly isolated plaque islands limited to one tooth surface at the bracket base. According to the graded interpretation system by Beberhold et al. (2012)[39], this corresponds to “good” oral hygiene, with a prophylaxis need limited to remotivation, maintenance of recall interval, and local fluoridation. By T1, the mean OPI increased to 1.91, reflecting plaque accumulation on two tooth surfaces near brackets in most patients falling within the “mediocre” oral hygiene category. This level necessitates oral hygiene instruction,

professional tooth cleaning, and reinforcement of hygiene techniques, in addition to continued fluoridation. At T2, the mean OPI reached 2.61, suggesting that three or more surfaces were affected, or that gingival inflammation was present in multiple patients. This level corresponds to “inadequate” oral hygiene, requiring more intensive prophylactic measures such as shortened recall intervals, professional tooth cleaning, targeted oral hygiene instruction, and, if necessary, chlorhexidine therapy.

This progressive deterioration in oral hygiene is consistent with existing literature. Atassi and Awartani (2010) reported a significant rise in plaque index within the first three months of treatment, similar to the increase from 1.03 at T0 to 1.91 at T1 in this study [37]. Cantekin et al. (2011)[38] further observed that plaque index values continued to worsen by the six-month point, paralleling the finding of 2.61 at T2 in this study, reflecting reduced patient compliance and mechanical limitations imposed by orthodontic appliances. Mahindra et al. (2017)[47] confirmed that orthodontic patients demonstrate a sustained decline in oral hygiene and gingival health.

Kumar et al. (2021)[53] specifically emphasized the challenge of maintaining hygiene, which aligns with the findings in this study where the most substantial OPI increase occurred between T1 and T2 (from 1.91 to 2.61), indicating the critical need for professional intervention and possibly incorporating adjunctive therapies like chlorhexidine rinses. Anuwongnukroh et al. (2017)[45] similarly observed that without consistent professional hygiene reinforcement, patients' OPI scores progressed into the 3–4 range within six months, with associated clinical signs of gingivitis and enamel demineralization.

Beberhold et al. (2012)[39], who introduced the OPI scoring system, emphasized that values above 2 are indicative of high caries and gingivitis risk, aligning with the T2

score in this study and reinforcing the need for early intervention strategies in orthodontic care.

Pinto et al. (2017)[49] also linked plaque accumulation with the development of gingival overgrowth and treatment duration of fixed appliance therapy, further reinforcing the biological significance of rising OPI scores. Almutairi et al. (2023)[57] recommended combining mechanical and chemical plaque control methods for patients whose OPI scores trend above 2, particularly between the third and sixth months of treatment consistent with the findings in this study.

In conclusion, the steady rise in OPI values from 1.03 at T0 (good hygiene) to 2.61 at T2 (inadequate hygiene) in this study reflects the cumulative impact of fixed appliances on oral hygiene status. These findings align closely with previous literature and highlight the critical role of regular oral hygiene instruction, shortened recall intervals, professional cleaning, and possible chemotherapeutic support to manage plaque accumulation. The OPI proved to be an effective, treatment-specific index that not only assessed hygiene status but also directly guided clinical decisions for prophylaxis needs across different treatment stages.

- **Discussion of Correlation of Delta E and Oral Hygiene Status for Maxillary Arch.**

In this study, a statistically significant moderate positive correlation ($r = 0.472$, $p = 0.007$) was observed between tooth color change (ΔE) and oral hygiene status in the maxillary arch among patients undergoing fixed orthodontic treatment. The mean ΔE values in this group ranged between clinically noticeable levels, confirming that as oral hygiene worsened, tooth discoloration increased. A total of 32 patients were evaluated, and this relationship suggests that poor oral hygiene contributes to visible enamel color

changes, likely due to plaque accumulation and demineralization around brackets and wires.

These findings are consistent with earlier studies. For example, Karamouzos et al. (2010)[36] reported ΔE values ranging from 2.12 to 3.61 in patients after fixed orthodontic treatment, confirming visible color changes especially in the presence of chemically cured adhesives. Kaya et al. (2018)[50] also noted ΔE values between 1.52 and 3.57 during the retention period, with the most significant color change observed within the first 3 months post-treatment. Similarly, Santos et al. (2021)[55] found that ΔE values after one year of treatment were significantly higher around the areas where brackets had been bonded, with composite resin adhesives causing more discoloration than resin-modified glass ionomer cements. These values are comparable to the mean ΔE range observed in our study and underline the clinical relevance of color changes associated with orthodontic appliances.

Alongside this, numerous studies have documented a decline in oral hygiene during orthodontic treatment, which may contribute to the observed increase in ΔE. Zachrisson (1971)[27] found that patients with higher plaque index (PI) and gingival index (GI) scores had a higher caries incidence, especially on smooth surfaces around banded teeth. Atassi and Awartani (2011)[37] reported that 60% of orthodontic patients had poor oral hygiene, based on Orthodontic Plaque Index (OPI) and Gingival Bleeding Index (GBI) scores. Mahindra et al. (2017)[47] recorded very high mean scores for PI (65.24), GBI (19.14), and OPI (53.56), indicating widespread plaque accumulation despite regular brushing. These values mirror the deteriorated hygiene patterns noted in the present study, where worsening oral hygiene status was associated with greater ΔE values.

Kumar et al. (2021)[53] observed plaque index values increasing from 1.06 (at the first visit) to 1.40 by the end of treatment, indicating reduced long-term compliance. Pinto et al. (2017)[49] demonstrated that plaque index scores increased with the duration of treatment, especially after 1–2 years. Yadav et al. (2023)[56] reported initial improvements in PI and GBI during the first two weeks of treatment, but no further progress afterward, showing how patients may struggle to maintain good hygiene over time. Furthermore, Zhao et al. (2024)[61] found that even when brushing frequency improved, plaque scores remained high after six months, suggesting that brackets create niches where plaque persists.

Together, these studies strongly support the results of our investigation. Our correlation value of $r = 0.472$ indicates a moderate link between increasing ΔE and worsening oral hygiene, which is reinforced by similar findings from both color change studies (with ΔE values above 2.0) and hygiene studies (with PI and OPI scores steadily increasing during treatment). These results highlight the need for stronger hygiene education, regular reinforcement, and use of additional aids like interdental brushes, mouthwashes, and frequent professional cleanings to help minimize enamel discoloration and maintain aesthetics during fixed orthodontic therapy.

Conclusion

CONCLUSION

The study concludes that:

1. Lightness (L)

A consistent decrease in L values was recorded from T0 (baseline) to T2 (6 months), indicating a visible darkening of teeth during treatment.

The greatest reduction in lightness was observed on the mesial surface of the left lateral incisor (22), with a mean ΔL of −5.10, followed by 22C (−4.91) and 21C (−4.56).

The least change in lightness occurred on the distal surface of the right canine (13) with a mean ΔL of −1.02.

These results suggest that cervical and mesial surfaces are more prone to discoloration, likely due to plaque retention and limited access during cleaning.

2. Chroma (C)

A noticeable increase in C values was recorded over time, reflecting a shift toward more saturated and intense tooth color.

The highest increase in C occurred on the mesial surface of the right canine (13M) with a mean change of +2.98, followed by 13C (+2.72) and 12C (+2.61).

The least chroma change was noted on the distal surface of the right central incisor (11D) with a mean ΔC of +0.56.

These findings indicate that mesial and cervical surfaces are more vulnerable to changes in color intensity during treatment.

3. Hue (h)

Changes in hue angle (h) were generally minor and not statistically significant.

The highest hue increase was found on the incisal surface of the left canine (23) with a

mean Δh of +7.82, while the least change occurred on the cervical surface of the right canine (13) with a mean Δh of +0.54.

This indicates that while there were small shifts in the perceived shade of enamel, the hue remained relatively stable throughout the study period.

4. Overall Colour Change (ΔE)

The ΔE values reflected the cumulative change in tooth color and showed visible discoloration across several surfaces.

The highest ΔE was recorded on the mesial surface of the left lateral incisor (22M) with a mean value of 6.78, followed by 21 (6.50) and 22 (6.43).

The least ΔE was observed on the distal surface of the right canine (13) at 2.18.

As ΔE values above 2.0 are considered clinically perceptible, these findings confirm that most patients experienced visible enamel discoloration during treatment.

5. Oral Hygiene Status

Oral hygiene was assessed using the Orthodontic Plaque Index (OPI) at all three time points. The mean OPI score increased from 1.03 at T0 (indicating good hygiene) to 1.97 at T1 and 2.61 at T2, reflecting a progressive decline in hygiene throughout the six-month treatment period.

This trend suggests that fixed appliances contribute to increased plaque accumulation and reduced cleaning efficiency over time.

6. Correlation Between ΔE and Oral Hygiene

A moderate positive correlation was observed between ΔE values and OPI scores, with Pearson's correlation coefficient $r = 0.472$ and a p-value of 0.007 ($N = 32$).

This statistically significant relationship indicates that poorer oral hygiene is associated

with greater enamel color change, confirming that plaque accumulation plays a direct role in tooth discoloration during orthodontic therapy

Summary

SUMMARY

The present observational study was designed to evaluate longitudinal alterations in tooth color parameters Lightness (L), Chroma (C), Hue angle (h), and overall color difference (ΔE) as well as changes in oral hygiene status of patients undergoing fixed orthodontic therapy over a six-month period. The primary objectives were to assess changes in tooth color of maxillary anterior teeth at three defined time intervals T0 (baseline, day of bonding), T1 (3 months post-bonding), and T2 (6 months post-bonding); to identify the specific maxillary anterior tooth (central incisor, lateral incisor, or canine) and surface (cervical, mesial, distal, incisal) exhibiting the most pronounced color change; and to quantify alterations in oral hygiene using the Orthodontic Plaque Index (OPI). The study sample comprised 32 subjects undergoing comprehensive fixed orthodontic treatment. Objective color measurements were recorded using the VITA Easyshade® spectrophotometer under standardized lighting conditions, while oral hygiene was assessed clinically via the OPI. Statistical analyses were performed using repeated measures ANOVA to evaluate intra-subject differences across time points for each color parameter, followed by Tukey's post hoc test for pairwise comparisons. Pearson correlation analysis was applied to determine the relationship between ΔE values and OPI scores.

The results demonstrated a statistically significant reduction in L values across all maxillary anterior teeth, indicating a progressive darkening of enamel surfaces throughout the study period. The most substantial decrease in L was observed at the mesial surface of the left lateral incisor (22) with a mean ΔL of −5.10. Chroma (C) values increased significantly from T0 to T2, particularly at the mesial and cervical regions, with the highest mean increase recorded at right maxillary canine (+2.98),

indicating an enhancement in color saturation. Hue angle (h°) exhibited variable changes, with the maximum shift noted at left canine (+7.82), although these differences were not statistically significant across most surfaces. ΔE values exceeded the clinical perceptibility threshold (ΔE > 2.0) in multiple sites, with the highest value reported at left lateral incisor (6.78), signifying perceptible color changes during the fixed appliance phase. A progressive decline in oral hygiene status was also recorded, as reflected by the OPI scores, which increased from a mean of 1.03 at T0 to 2.61 at T2, indicating a shift from good to inadequate oral hygiene. A statistically significant moderate positive correlation was identified between ΔE and OPI ($r = 0.472$, $p = 0.007$), suggesting that greater enamel color change was positively associated with worsening oral hygiene.

In conclusion, this study confirms that fixed orthodontic appliances contribute to clinically significant alterations in enamel optical properties, particularly in terms of lightness and chroma, with mesial and cervical surfaces being most affected. Concurrently, a marked deterioration in oral hygiene was observed during the treatment course. The significant correlation between ΔE and OPI underscores the etiological role of plaque accumulation in the development of enamel discoloration. These findings highlight the imperative for stringent oral hygiene maintenance, preventive strategies, and regular professional prophylaxis to mitigate esthetic compromise and maintain enamel integrity throughout orthodontic therapy.

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Annexure

ANNEXURE – I

SANTOSH
Deemed to be University
(Established u/s 3 of the UGC Act, 1956)

INFORMED CONSENT

DEPARTMENT OF ORTHODONTICS AND DENTOFACIAL ORTHOPEDICS

SANTOSH DENTAL COLLEGE AND HOSPITAL, GHAZIABAD

I, Mr. / Ms.

……..

S/O, D/O, W/O. ……..

Resident of

……

I am willingly participating in this study and I have been informed about all the benefits and there are no risks during and after this procedure. I am willingly participating in the study conducted by the department of Orthodontics and Dentofacial orthopedics, Santosh Dental College and Hospital.

I should choose to withdraw from this study at any point; I will be free to do so after giving prior information to the concerned surgeon.

Signature of Surgeon In-charge

Signature of Patient

Date: Signature of Parent/Guardian

Date:

ANNEXURE – II

MASTER CHART

S.NO	AGE	SEX	Time	Oral hygiene status		
				upperarch	lower arch	oral hygiene of dentition
1	19	Female	T0	2	1	2
2	15	Female	T0	2	2	2
3	15	Female	T0	1	2	2
4	18	Female	T0	3	3	3
5	17	Male	T0	2	1	2
6	17	Female	T0	2	1	2
7	21	Female	T0	2	1	2
8	17	Male	T0	3	2	3
9	30	Female	T0	3	3	3
10	23	Female	T0	2	2	2
11	21	Female	T0	2	1	2
12	16	Female	T0	2	2	2
13	21	Male	T0	3	2	3
14	16	Male	T0	2	2	2
15	19	Female	T0	3	2	3
16	17	Female	T0	3	3	3
17	18	Female	T0	3	3	3
18	19	Female	T0	2	2	2
19	18	Female	T0	3	1	3
20	14	Female	T0	2	1	2
21	22	Female	T0	2	2	1
22	18	Male	T0	2	2	2
23	14	Female	T0	1	1	1
24	28	Female	T0	1	2	2
25	27	Female	T0	3	3	3
26	22	Female	T0	2	1	2
27	19	Male	T0	3	3	3
28	23	Female	T0	2	2	2
29	21	Female	T0	2	2	2
30	18	Female	T0	3	1	3
31	18	Male	T0	2	2	2
32	18	Female	T0	3	1	3

S.No	Time	L(lightness) of maxillary right central incisor				L (lightness) of maxillary right lateral incisor			
		Cervical	Mesial	Distal	Incisal	Cervical	Mesial	Distal	Incisal
1	T0	+2.4	+2.8	+2	-7.6	+0.2	-1.6	-2.3	-11.2
2	T0	+5	+4.6	+2.4	+2.3	+5.7	+5.7	+5	+6.5
3	T0	+1.3	+5.9	+6.6	+8.3	+4.2	+6.5	+4.2	+6.5
4	T0	+3.11	+3.5	+4	+9.4	-3.1	+11.7	+7.6	+12.1
5	T0	+0.6	-1.4	-1.5	+1.9	+3.6	-2.3	-4.9	-1.2
6	T0	+1.1	-28	-2.1	-4.8	1.7	-10.1	7.5	+1
7	T0	+2.7	-2.8	+2	-7.7	+0.3	-1.7	-2.9	-11.9
8	T0	+3.7	+3.7	+5.6	+0.5	+5.1	+2.3	+7.4	+6.3
9	T0	+1.9	+2.3	+4.5	+7.2	+6.5	+1.2	+8.2	+2.5
10	T0	+1.3	+5.9	6.6	+8.3	+4.2	+6.5	+4.2	+6.5
11	T0	-2.8	-6.7	-9.4	-18.1	-8	-4.7	-6.6	-7.1
12	T0	-0.9	-3.5	-0.7	-10.5	-5.3	+0.4	-2.9	-12.0
13	T0	+3.9	+9.9	6.8	+4.2	+2.2	+1.8	-0.1	+4.7
14	T0	-6.6	-0.4	-9	-4	-2.3	-1	-1.6	-0.4
15	T0	+8.5	-4.4	-11.5	-3.1	+9.3	-4.2	-14.4	-8.7
16	T0	-2.9	-6.7	-9.4	-13.2	-6.2	-7.1	+1.6	-11.2
17	T0	+3	+6.8	+3.9	+9.7	+2	+11.7	+7.8	+12.7
18	T0	+2.4	-2.8	+2	7.6	+0.2	-1.6	-23	-11.2
19	T0	-0.3	+3.9	+4.6	+8.2	+9.6	+9.6	+5.2	+6.2
20	TO	+3.4	3.3	+0.7	+1.4	+0.8	3.3	-0.8	-0.4
21	T0	+6.6	+1.6	+5.5	-4.7	+1.7	+0.4	+3.9	+7.5
22	T0	+3.3	-8.5	-1.1	-7.8	-6.7	-6.5	-8.8	-5.4
23	T0	+3.4	3.3	+0.7	+1.4	+0.8	3.3	-0.8	-0.4
24	T0	+5.5	+4.5	+0.9	-1	-0.1	-1.5	+2.7	-1.0
25	T0	3.17	5.17	1.13	9.16	7.4	7.4	3.18	5.18
26	T0	-8.9	-5.4	-2.3	-7	+4.9	-3.6	-12.3	-10.1
27	T0	+1.3	+1.7	+1.3	-3.1	-4.4	-15.8	-15.7	-10.3
28	T0	9	-5.8	8.3	8.4	+2	-12.6	-12.7	-2.3
29	T0	+8.3	-6.9	-8.3	-13	-13.4	-13.6	-9.1	-15.4
30	T0	-6.1	-2.6	-5.5	-8.3	-7.1	-13.3	-7.06	-8.6
31	T0	-7.5	-2.7	-5.2	-5.9	-9.7	-11.5	-11.9	-5.1
32	T0	-9.1	-11.8	-14.4	-0.1	+4.3	-9.4	+0.6	-5

S.No	Time	L (lightness) of maxillary right canine				L (lightness) of maxillary left central incisor			
		cervical	mesial	distal	incisal	cervical	mesial	distal	incisal
1	T0	+4	+3.2	+3.9	0.4	5	3.2	2.9	-3.2
2	T0	+9.8	+6	5.1	5	3.6	3.4	5.4	0.4
3	T0	+7.1	+2.6	7.6	4.1	2.5	1.7	2.1	4.4
4	T0	+10.8	+11.2	11.8	10.1	1.3	5.9	6.6	8.3
5	T0	-3.6	+5.2	+3	+2.2	-4.8	+0.3	-0.7	-0.8
6	T0	-1.2	-6.7	-2.9	+2.0	+6	4.7	-5.7	-3.7
7	T0	+4.3	+3.4	+3.5	+0.5	+5	+3.4	+2.9	-3.5
8	T0	+9.5	+2.1	+7.4	+2.7	+5.1	+4.6	+3.6	+2.7
9	T0	+9.8	-1.3	-1.8	+2.1	+6.5	+4.2	+4.5	-2.5
10	T0	+7.1	+2.6	-7.6	+4.1	+3.1	+3.5	+4	19.4
11	T0	+16	-11.1	-1.9	+2.6	-2.3	-3.6	-1.4	-2.8
12	T0	-11.9	+0.4	+2.3	-5.3	-10.9	+0.8	-5.8	-8.6
13	T0	+9.5	+6.6	+7.9	-5.1	+3.9	+9.9	6.8	+4.2
14	T0	-2.7	-6.8	-7.4	-7	-5.9	-2.2	-1.9	-2
15	T0	-16.5	-15.6	-10.7	-4.1	5.4	7	-5.8	-2.9
16	T0	-1.9	+2.3	-2.6	+6.5	+3.8	+10.2	+6.2	+4.2
17	T0	+10.11	+11.4	+12.8	+10.1	+3.7	+9.6	6.8	+4.2
18	T0	+4	+3.2	+3.9	-0.9	+4.2	+2.5	-2.4	+1.2
19	T0	+5.3	+5.6	+8.3	+6.7	+8.6	+1.5	+12.6	-0.7
20	TO	+7.6	+3.6	+2.6	-1.5	+5	+1.6	+22	-09
21	T0	+3.1	+1.5	+2.8	+0.5	+4.0	+3.6	+3.3	-0.9
22	T0	-0.5	-8	-14.2	-4.6	+4.5	-8.9	-10.3	-4.5
23	T0	+7.6	+3.6	+2.4	-1.5	+5	+1.6	+2.2	-0.9
24	T0	-1.6	-11.2	-12.9	-3.6	+3.4	-3.6	-2.4	-7
25	T0	1.14	9.17	7.4	7.4	3.19	5.19	1.15	9.18
26	T0	-11	-10.6	-13.2	-3.1	-15.5	-8.7	-4.7	-11.3
27	T0	-8.3	+3.9	-3.7	-6.5	-3.2	-2.1	-3.5	-6.7
28	T0	-8.8	-6.8	+0.1	-8.3	+0.9	7.5	-3.5	+2
29	T0	-1.6	-8.5	-4.3	-8.9	-3.9	-4.3	+1.5	+0.9
30	T0	-7.6	-8.6	-7.9	-4.4	-3.1	-8.5	-7.1	-28.4
31	T0	+7.7	-10.2	-4	+9.5	-1.5	-1.9	-8	-15.6
32	T0	-7	-2.5	-12.2	-7.6	+9.1	-3.4	-6.8	+0.1

S.No	Time	L (lightness) of maxillary left lateral incisor				L (lightness) of maxillary left canine			
		cervical	mesial	distal	incisal	cervical	mesial	distal	incisal
1	T0	4.5	3.4	2	1.6	6.4	2.7	5.3	5
2	T0	5	4.3	7.2	6.2	9.1	2	7.2	5.1
3	T0	1	5	4.8	4.2	5.4	2.4	-7.4	-1.2
4	T0	4.2	6.5	4.2	6.5	7.1	2.6	-7.6	4.1
5	T0	+5.9	-7.7	+4.4	-4.1	-1.4	+1.2	+1.5	+1.7
6	T0	-1.8	-4.9	+6.2	+4.7	+3.6	+3.7	+2.8	+4.2
7	T0	+5.1	+3.9	+2.1	+1.80	+6.4	+2.8	+5.3	+5.1
8	T0	+5.7	+5.9	+5	+6.5	+9.8	+6	+5.1	+5
9	T0	+6.2	+8.9	+0.2	+5.2	+8.5	+3.2	+6.2	+4.2
10	T0	-3.1	+1.7	7.76	+12.1	+10.8	+11.2	+11.8	71.1
11	T0	-3.4	-3.3	+8.8	+2.5	+2.6	-5.2	-4.1	-6.2
12	T0	+6.2	-9.8	-7.8	-6.8	+0.8	+2.2	+38	+1
13	T0	+2.2	1.8	-01	+4.7	+9.5	+6.6	+7.9	-5.1
14	T0	-6.5	-10	-12.1	-3.2	+3.2	+1	-2.6	+2.6
15	T0	4.2	-5.2	4.9	-2	-10.7	-2.2	-7.5	2.1
16	T0	+2.2	+8	-0.2	+4.8	+4.8	+5.5	+1.2	+5.2
17	T0	+2.2	+8	-0.1	+4.7	+9.5	+5.8	+7.9	+5.1
18	T0	+2.6	+5.1	-3.8	-9.5	+6.5	+2.6	+5.5	+3.5
19	T0	-3.2	+.39	+3.4	+2.7	-2.5	-1.8	-3.7	-3.6
20	TO	+7.6	+4.8	+5	+1.9	+4.1	0.2	+6.1	+2
21	T0	+3.3	+2	+3.8	-0.2	6.9	+7.3	+3.8	+1.5
22	T0	-13.2	-1.4	-6.3	+2.5	+5.9	-3.2	-8.4	-4.9
23	T0	+7.6	+4.8	5	+1.9	+4.1	+0.2	+6.1	+2
24	T0	-2.9	-2.5	-6	+0.7	-7.3	+3.2	-6.9	-0.3
25	T0	7.4	7.4	3.20	5.20	1.16	9.19	7.4	7.4
26	T0	-9.3	-8.9	-6.7	+3.6	-7.2	-13.5	+0.1	+0.3
27	T0	+1.6	-11.1	-5.9	-9.0	-4.9	-6.5	-9.9	-3.4
28	T0	+0.9	+3.2	-6.3	+2.7	-7.9	-3.6	-1	-2.8
29	T0	-6.9	-8.4	-14.6	-9	-9.8	-9.8	-8	-5.3
30	T0	+0.7	+2	+2.9	+0.1	-6.3	-6.7	+2.1	+1.2
31	T0	-11.3	-15.2	+0.6	-1.9	-5.6	-5.1	-14.7	-8.7
32	T0	+4.7	-7.1	-10	-4.6	-1.2	+1.1	-4.6	-7.1

S.No	Time	C (chroma) of maxillary right central incisor				C (chroma) of maxillary right lateral incisor			
		cervical	mesial	distal	incisal	cervical	mesial	distal	incisal
1	T0	0.5	4.1	-3.2	-4.8	-0.9	-4.1	-3.6	-6
2	T0	5.6	2.7	3.5	1	5.8	4.4	4.4	1.5
3	T0	1.8	1.6	1.6	0.5	1.2	2.6	1.2	2.6
4	T0	6.7	3.7	4.5	3.1	-1.1	3	1.8	2.4
5	T0	-2.6	+2.2	+0.2	+5.8	-12.3	+0.3	+0.0	+1.8
6	T0	-0.5	-4.1	-2.7	-9.8	0.2	+2.8	-10.2	-0.6
7	T0	+.07	-4.2	-3.9	-4.9	-0.5	-4.3	-3.6	-6.5
8	T0	+4.2	+2.7	+1.7	+0.1	+4.7	+4.5	+4.1	+4.5
9	T0	+1.6	+1.8	+8.2	+5.2	+6.2	+6.2	+6.5	+9.2
10	T0	+1.68	+1.8	+1.6	+0.5	+1.2	+2.6	+1.2	+2.6
11	T0	-2.1	-5.7	-3.2	-5.7	-8.4	-3.4	-8.7	-9
12	T0	+0.9	+0.7	+1.9	-4.5	-1.3	-1.5	-1	-6.8
13	T0	+5.5	+5.4	+6.3	+2.6	+3.9	+2.7	+4.4	+3.6
14	T0	-3.4	-1.2	-6.7	-0.3	-2.9	-0.9	+1.7	-5
15	T0	+4	-1	-7.2	+0.9	+7	-0.8	-4.2	-4.7
16	T0	-2.1	+5.4	+6.3	+2.6	13.9	+2.7	+4.5	+3.6
17	T0	+6.7	+3.7	+4.3	+3.1	-1.1	+3	+1.8	+2.5
18	T0	+0.5	-6.3	3.2	-4.8	-0.9	-4.1	-3.6	-6
19	T0	-2.3	+1.9	+2.6	+1.2	+2.8	+3	+0.2	+1.7
20	TO	+3	1.2	+1.6	+1.2	-0.4	-0.4	+2.7	+3.1
21	T0	3.4	2.4	3.3	+0.1	5.2	3.7	-0.1	4.1
22	T0	+1.6	-5	-0.9	-6	-0.6	-3.5	-2.9	-9.9
23	T0	+3	1.2	+1.6	+1.2	-0.4	-0.4	+2.7	+3.1
24	T0	+2.4	+1.8	+3.2	-2.4	+0.1	-1.6	-1.4	-6.9
25	T0	3.25	5.25	1.21	9.24	7.4	7.4	3.26	5.26
26	T0	-3.2	-3.6	-0.5	-5.7	-0.7	-0.3	-6.8	-10.2
27	T0	-1.5	+0.0	+0.4	-1.5	-2.1	-7.7	-9.2	-9.8
28	T0	3.7	-6.8	+1.4	-8.4	+1.9	-6.1	-4	-16.7
29	T0	+4.3	-2.4	-6.1	-4.6	-4	-3.5	-6.6	-4.1
30	T0	-6	-2.6	-2.9	-5.2	-7.4	-7.2	-3.8	-8.8
31	T0	-2	-7.1	-6.4	-6.3	-2.6	-5.2	-5.5	-8.9
32	T0	-2.1	-4	-7.2	-1.1	-0.8	-6.5	-2.3	-3.7

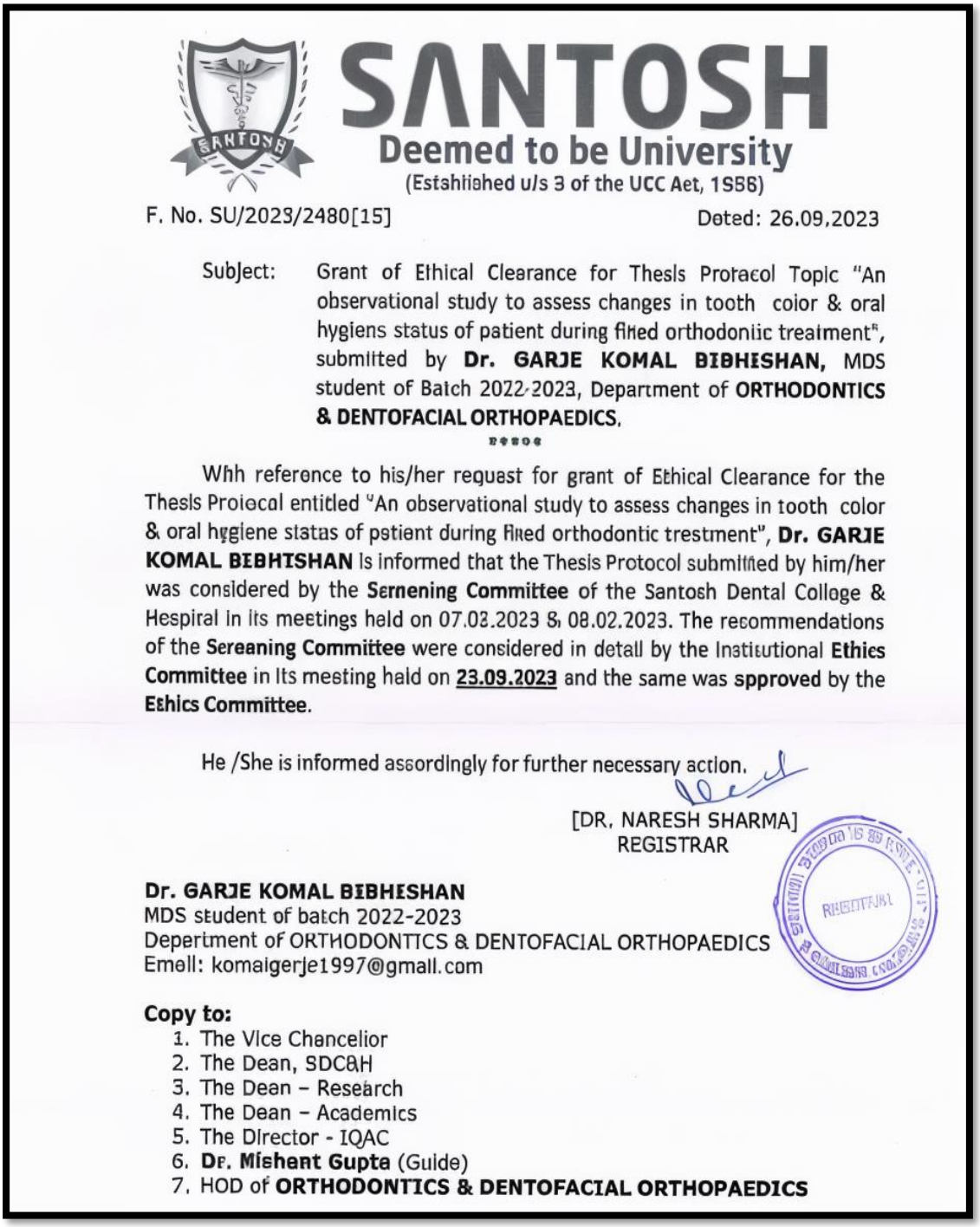
S.No	Time	C (chroma) of maxillary right canine				C (chroma) of maxillary left central incisor			
		cervical	mesial	distal	incisal	cervical	mesial	distal	incisal
1	T0	4	1.3	1.9	-0.3	-0.6	-4.8	-5.2	-5.1
2	T0	4.8	3.5	2	2.9	4.1	2.1	1.4	0
3	T0	5.1	1.8	1.4	2.8	0.3	3.3	0.4	1.7
4	T0	5.11	7.9	5.9	5.7	1.68	1.8	1.6	0.5
5	T0	+2.7	+1.5	-10.2	+0.4	-5	+2.3	-1.7	-3.4
6	T0	-4.7	-3.1	-3	+5.	+6	4.7	-5.7	-3.7
7	T0	+4.2	+1.7	+1.9	-0.3	-0.6	-4.9	-5.2	-5.1
8	T0	+5.4	+0.7	+3.6	+2.4	+5.6	+2.7	+3.5	+1
9	T0	+5.2	+1.9	+7.6	+6.2	+3.1	+3.1	+2.9	-0.5
10	T0	+5.1	+1.8	+1	+2.8	+6.7	+3.7	+43	+3.1
11	T0	-3.3	-4.2	-11.3	-15.4	+1.2	+0.5	-0.4	-15.8
12	T0	-3.6	-1.5	-0.07	-3.	-9.2	15.4	-3.5	-2.4
13	T0	+6.1	+5.8	+6.2	+4.6	+2.8	+4.4	+3.8	+1.7
14	T0	-2.8	-5.5	-6.5	-14.4	-0.7	-5.1	-1.3	+0.2
15	T0	-5.5	-4	-7.4	0.2	5.3	0.4	-0.7	0.6
16	T0	+6.2	+5.9	+6.3	+4.6	+2.9	+4.2	+3.9	+1.8
17	T0	+5.11	+7.8	+5.4	+5.7	+2.9	+4.6	+3.8	+1.7
18	T0	+4	+1.3	1.9	-0.3	-5.3	-5.9	-4.5	-6.5
19	T0	-0.8	+0.1	+2.2	+0.9	+2.6	+1.9	+3.4	-7.3
20	TO	+5.2	+3.6	+3.2	-2.3	+5	+1.6	+22	-09
21	T0	2.7	+0.9	+3.1	+1.1	1.8	2	-3.7	+2.5
22	T0	-1.8	-4.2	-5.3	-1.1	-2.4	+7.2	+8.2	-15.7
23	T0	+5.2	+3.6	+3.2	-2.3	+3.1	+2.7	+3.7	+2.5
24	T0	+0.2	-6.7	-8.1	-1.4	3.5	-0.8	+1.7	-6.3
25	T0	1.22	9.25	7.4	7.4	3.27	5.27	1.23	9.26
26	T0	-8	-12	-10	-8.4	-7.7	-2.6	-7.9	-3.5
27	T0	-7.3	+0.7	-5.9	-4.9	+1.5	-3	-2.4	-5.9
28	T0	-5.8	-8.6	-5.6	-10.2	-0.0	-7.8	-6.2	-13.1
29	T0	-2.3	-6.8	-2.2	-8.1	-6.4	-0.9	-4.3	-5.6
30	T0	-6.2	-4.2	-1.7	-7.9	+0.5	-10.9	-18.3	-19.6
31	T0	-1.9	-9.8	-8.9	-0.5	-8.5	-2.2	-5.8	-4.1
32	T0	-3.7	+1.4	-7.4	-0.2	+2.7	-3.1	-3.2	-2.9

S.No	Time	C (chroma) of maxillary left lateral incisor				C (chroma) of maxillary left canine			
		cervical	mesial	distal	incisal	cervical	mesial	distal	incisal
1	T0	-1.3	-9	-3	-4.6	4.6	1.8	3.5	2.9
2	T0	4.7	4.3	4.9	4.4	5.3	0.5	3.5	2.4
3	T0	-0.2	1.3	1.3	1.2	3	-0.6	-1.2	0.6
4	T0	1.2	2.6	1.2	2.6	5.1	1.8	1.6	2.8
5	T0	+2.5	+13.4	+4	-5.2	+4.2	-5.2	-8.3	+3.8
6	T0	-1.8	-4.9	+6.2	+4.7	+3.6	+3.7	+2.8	+4.2
7	T0	-1.3	+4	-1.3	-4.8	+4.7	+1.9	+5.9	2.9
8	T0	+5.9	+4.9	+4.4	+1.5	+4.8	+3.9	+2	+2.9
9	T0	+3.3	+2.9	+3.2	+0.9	+3.1	+3.2	+0.5	+4.3
10	T0	-1.1	+3	+18	+2.4	+5.11	+79	+5.4	+5.7
11	T0	-3	-2.7	-12.9	-14.1	+6.1	-12.3	-4	-6.9
12	T0	+2.8	-3.9	-8.8	-2.7	-0.2	+2.2	+1	-1.6
13	T0	+2.5	+3.4	+2.3	+3.6	+3.7	+3.7	+2	4.2
14	T0	-5.4	-4.9	-7.2	-4	+0.4	-2.6	-10.8	+0.6
15	T0	2.1	-0.4	-3.7	-0.5	-5.4	-3.6	-7.1	-2.3
16	T0	+2.8	+3.8	+2.8	+3.8	+3.7	+3.2	+2.2	+4.2
17	T0	+2.5	+3.4	+2.3	+3.8	+3.2	+3.7	+2	+4.2
18	T0	+10.6	-2.5	-2.5	-6.3	-1.3	-1.2	-1.2	-0.5
19	T0	-10.3	-7.4	-7.2	-8.5	-0.9	-1.8	-0.6	-0.6
20	TO	+7.6	+4.8	5	+1.9	+4.1	+ 0.2	+6.1	+2
21	T0	4.9	2	-2	+2.9	-0.1	4.1	-4.6	1.1
22	T0	-5.7	+5	+11.6	+13.9	-4.6	-1.1	+1.4	+1.3
23	T0	+1.5	+3.9	1-3	+0.2	+3.5	+1.6	+1.5	+2.8
24	T0	-3.3	-1.5	-5.2	-6.2	-2.6	-0.9	-8.2	-0.5
25	T0	7.4	7.4	3.28	5.28	1.24	9.27	7.4	7.4
26	T0	-1.9	-7	-5.2	-11.6	-6.4	-9.1	+0.8	-8
27	T0	-14.6	-11	-10.5	-10.8	-0.5	-4	-6.6	-0.1
28	T0	+0.8	-12.2	6.6	+5.3	-6.0	-10.7	-3.7	-4.6
29	T0	-1.3	-5.3	-6.6	-4.4	-3.5	-3.8	-6.6	-9
30	T0	-2	-15.9	-14.7	-16	-5.6	-8.4	+1.2	+0.5
31	T0	-8.1	-6.8	-15.2	-2.9	-13.5	-10.1	-5.6	-6.1
32	T0	-0.4	-6.4	-5.7	-7.1	-2.4	-0.8	-8.7	-5.5

S.No	Time	h (hue) of maxillary right central incisor				h (hue) of maxillary right lateral incisor			
		cervical	mesial	distal	incisal	cervical	mesial	distal	incisal
1	T0	-4.1	4.3	3.9	11.8	-1.5	5.2	3.7	13.9
2	T0	-4.8	-2.1	-2	0.9	-4.1	-4	-4.1	-4.4
3	T0	-6.7	-0.7	-1.3	-5.3	-0.6	-0.6	-0.6	-0.6
4	T0	-8.11	-5.8	-7.5	-0.8	5.7	1.11	3.4	2.7
5	T0	-10	-13.5	-11	-15.8	+1.1	-12.5	-14.1	-19.9
6	T0	+1.4	+4.3	+22	+28	1.7	2.8	-0.2	-0.6
7	T0	-4.3	+4.4	+3.5	+11.9	-1.7	+5.4	+3.9	-13.9
8	T0	-6.6	-2.4	-0.1	+2.5	-4.9	-4.9	-4.2	+4.6
9	T0	-6.7	-0.7	-1.3	-5.3	-0.6	-0.6	-0.3	-0.2
10	T0	-6.7	-0.7	-1.3	-5.3	-0.6	-0.6	-0.6	-0.6
11	T0	-5.9	-4.5	-4.6	-2.7	-28.9	-5.7	-4.7	+1.3
12	T0	-6.2	-6.0	-6.1	-2.7	-10.7	-7.5	-0.7	+9.1
13	T0	-9.5	-3.4	-3	-2.6	-4.2	-2.7	-2.8	-2.9
14	T0	-13.8	-6.3	-2	-0.9	-17.2	-4.5	-10.7	-6.2
15	T0	+0.2	-3.9	+15.2	+1.2	-2.4	-2.1	+0.3	+6.9
16	T0	+1.6	-3.4	-3	-2.6	-4.2	-2.7	-2.9	-2.8
17	T0	-8.11	-5.8	-7.5	-0.8	+5.7	+1.11	+3.4	+2.7
18	T0	-4.1	+4.3	+3.9	11.8	-1.5	-5.2	+3	+13.9
19	T0	-0.4	-2.3	-2.8	-0.8	-2.1	-1.7	-1.3	-3.5
20	TO	-1.8	-1.7	-0.4	-1.1	-3.6	-1.3	-1.6	-2.5
21	T0	-1.8	-12	-09	+3.1	-2.8	0.1	-5.3	-4.7
22	T0	-5.1	+6	+1.9	+4.4	-14.1	+2.3	-13.4	+6.4
23	T0	-1.8	-1.7	-0.4	-1.1	-3.6	-1.3	-1.6	-2.5
24	T0	-3.4	-5.6	-3.5	-1.1	-4.6	-3.1	-3.6	+2.6
25	T0	3.33	5.33	1.29	9.32	7.4	7.4	3.34	5.34
26	T0	-6.4	-2.0	-2.4	+5.1	-5.9	-5.4	-0.6	-2.7
27	T0	-13.7	-6.3	-3.6	+0.7	29.9	+0.9	+18.4	-21.4
28	T0	-3.2	-3.2	-4.4	+4.8	-5.3	+2.5	-3.7	+10.2
29	T0	-13.9	-0.9	+1.2	+4.8	+3.7	-2.6	+1.6	+4.
30	T0	-5.1	-0.2	+1.5	+3	-1.6	+5.2	-2.3	-2.1
31	T0	-5.4	-5	+2.1	-1.4	+7.1	-3.4	+13.9	+1.5
32	T0	-5.1	-10.4	-5	-0.1	-11.7	+1	-10.7	-4

S.No	Time	h (hue) of maxillary right canine				h (hue) of maxillary left central incisor			
		cervical	mesial	distal	incisal	cervical	mesial	distal	incisal
1	T0	-5.5	-3	-2	2.2	-0.3	6.9	12.6	16.2
2	T0	-2.7	-2.5	-1.9	-2.5	-4.5	-2.3	-0.1	2.4
3	T0	-2.2	-1.7	0.1	-1	-1.2	-3.6	-1	-1
4	T0	-3.2	-4	-0.11	2.1	-6.7	-0.7	-1.3	-5.3
5	T0	-22.3	-7.5	-10.4	-23.4	-4.2	-13.1	-1.7	-5.3
6	T0	-3.1	-1.2	1.5	-1.2	+3.4	+1.6	+3	+9.5
7	T0	-5.6	-3.2	-2	+2.5	+0.4	+6.10	+12.7	16.3
8	T0	-3.1	-2.3	-2.4	-2	-4.8	+2.1	-2	+0.9
9	T0	+1.2	+2.2	+2.4	+3.5	-9.2	-7.8	-5.2	-3.2
10	T0	-2.2	-1.7	+6.1	-1.2	-8.1	+5.8	-7.5	-08
11	T0	-16.7	-8	-14.0	+4.5	-10.7	-9.2	-6.3	-0.3
12	T0	-7.3	-7.5	-5.2	+1.1	+4.4	+29	+8	+5.7
13	T0	-4.2	-4.7	-4.3	-4.6	-6.3	-1.2	-1.5	+1.1
14	T0	-5.5	-9.0	-4.3	-8.4	-11.7	-4	-6.4	-4.1
15	T0	+0.2	-0.4	-4.9	0.2	-4.6	-6.5	-1.8	-3.5
16	T0	+4.2	+4.2	+4.7	-4.3	-6.4	-1.2	-1.6	+1
17	T0	-3.2	-4	-0.11	+2.1	-6.3	-1.5	-1.7	+1
18	T0	-5.5	-3	-2	+2.2	+1	+14.4	+0.9	+21.3
19	T0	-3.4	-1.1	-1.8	-1.2	-1.7	-2.8	-1.7	-34.9
20	TO	-3.7	-4.4	-3.5	+0.4	-1.9	-3	-3.1	-32
21	T0	-4	-3	-5.1	-3.5	1.2	1.8	-1.1	1.5
22	T0	-4.1	-0.4	-22.7	+4.6	-2.4	+7.2	+8.2	-15.7
23	T0	-3.7	-4.4	-3.5	+0.4	-1.9	-3	-3.1	-3.2
24	T0	-1.9	-4	-12.1	-3.2	-3.3	-2.9	-4.6	+4
25	T0	1.30	9.33	7.4	7.4	3.35	5.35	1.31	9.34
26	T0	-30.3	-5.9	-9.5	-3.9	-1.3	-0.8	42.7	-0.9
27	T0	-15.3	+1.2	-5.5	-2.3	-10.4	-4	-3	+0.6
28	T0	-7.1	1.9	-3.1	-5.2	-3.1	+0.2	+2.6	+8.5
29	T0	-11.9	+1.9	-4.7	-3.5	4.8	-7	-1.6	-8.4
30	T0	-1	+1.7	-2	-2.9	-7.3	+10.4	+4.6	+2.0
31	T0	-9.5	+13.3	-5.4	+7.3	-14.6	1.3	-5.3	+13.3
32	T0	-2	-23.6	-11.3	-4.8	-4.5	+9.3	-5.7	-1.9

ANNEXURE – III



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Subject: Grant of Ethical Clearance for Thesis Protocol Topic "An observational study to assess changes in tooth color & oral hygiens status of patient during fixed orthodontic treatment", submitted by **Dr. GARJE KOMAL BIBHISHAN,** MDS student of Batch 2022-2023, Department of **ORTHODONTICS & DENTOFACIAL ORTHOPAEDICS**.

With reference to his/her request for grant of Ethical Clearance for the Thesis Protocol entitled "An observational study to assess changes in tooth color & oral hygiene status of patient during fixed orthodontic treatment", **Dr. GARJE KOMAL BIBHISHAN** is informed that the Thesis Protocol submitted by him/her was considered by the **Screening Committee** of the Santosh Dental College & Hospital in its meetings held on 07.02.2023 & 08.02.2023. The recommendations of the **Screening Committee** were considered in detail by the Institutional **Ethics Committee** in its meeting held on **23.09.2023** and the same was **approved** by the **Ethics Committee**.

He /She is informed accordingly for further necessary action.

[DR. NARESH SHARMA]
REGISTRAR

Dr. GARJE KOMAL BIBHISHAN
MDS student of batch 2022-2023
Department of ORTHODONTICS & DENTOFACIAL ORTHOPAEDICS
Email: komalgerje1997@gmail.com

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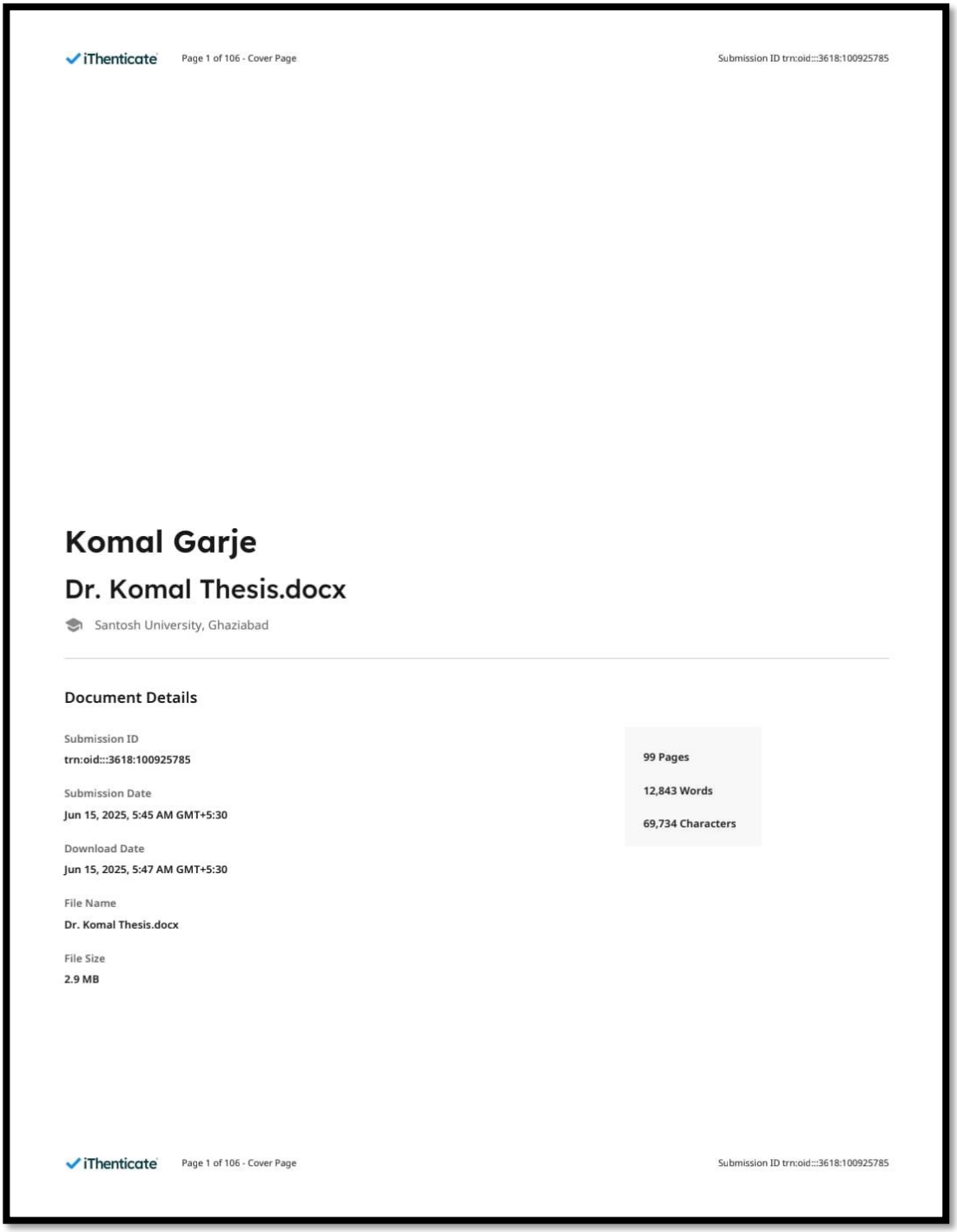
ANNEXURE – IV

ANTI-PLAGIARISM CHECK REPORT



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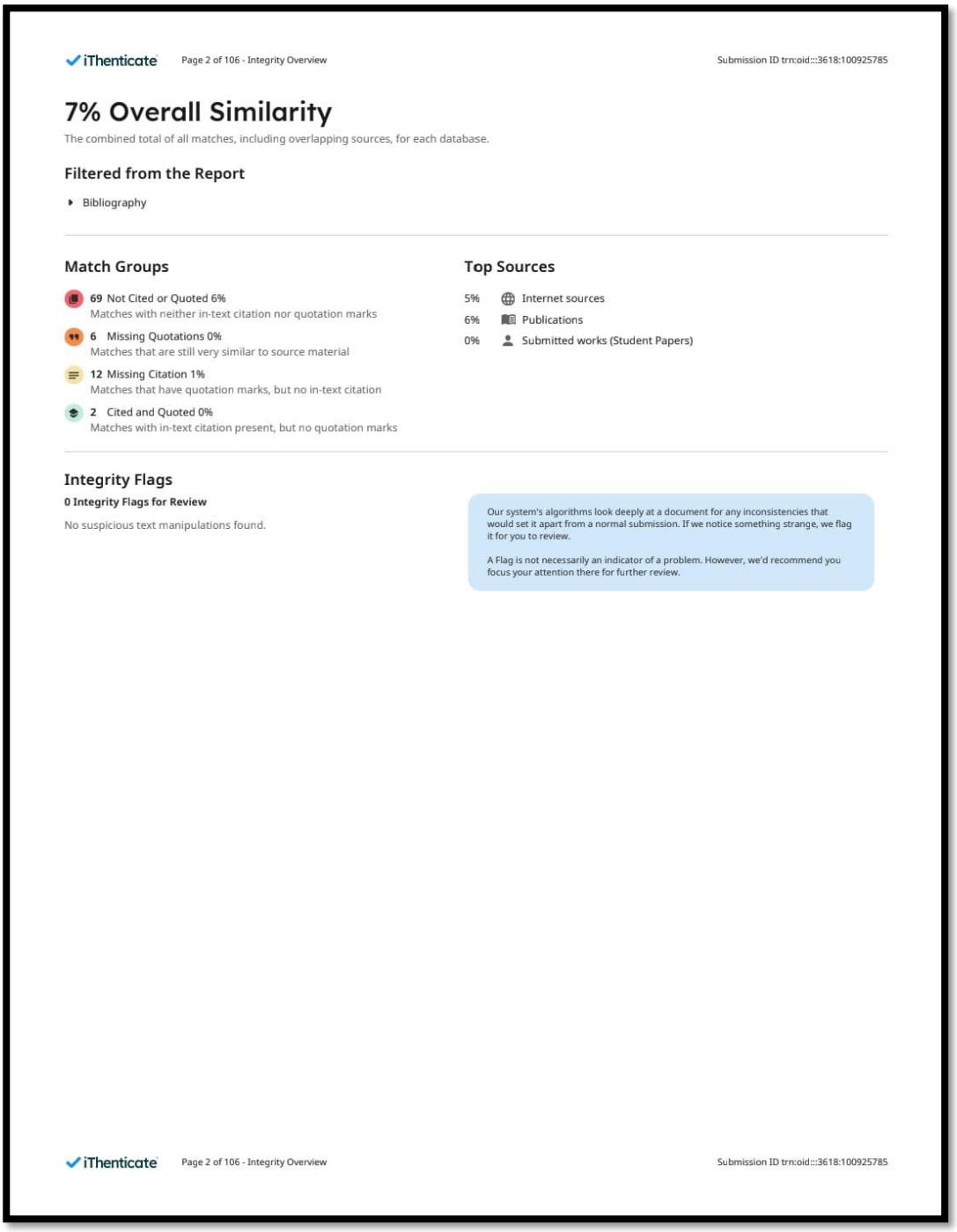

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